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SID 5 Research Project Final Report

Department for Environment Food and Rural Affairs

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Project identification

1. Defra Project code: AW0143
2. Project title: Re-designing the farrowing environment from first principles to optimise animal welfare and economic performance.
3. Contractor organisation(s): Newcastle University; SAC
4. Total Defra project costs (agreed fixed price): £693,206
5. Project: start date 1/4/2008
   end date 1/10/2011

6. It is Defra's intention to publish this form.
Please confirm your agreement to do so..**YES** ☒ **NO** ☐

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Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

Background:
There is growing pressure expressed by consumer demand, societal opinion and government legislation to abolish confinement systems such as the farrowing crate, which is both physically and behaviourally restrictive for the sow. However, producers have valid concerns regarding such change; they need to achieve good animal performance (i.e. high piglet survival), in systems with acceptable capital, running and labour costs, and which facilitate efficient labour routines and safeguard the operator. Hence, this project aimed to develop a suitable alternative to the farrowing crate that provides for the maximal sow and piglet welfare that can be achieved under commercial conditions. This required the re-designing of a system that could reconcile a ‘triangle of needs’ relating to the farmer, the sow and her litter. However, as the needs of the litter and the farmer are often closely aligned, the main conflict to be resolved lies between the sow and farmer. This embodies a conflict of how to provide the appropriate level of environmental enrichment to meet the biological ‘needs’ of the farrowing sow that is also consistent with good piglet survival, and other management and business constraints.

Objectives:
Overall objective: Design and commercially evaluate an alternative to the farrowing crate that provides for the maximal sow and piglet welfare whilst being commercially acceptable.

1. To review and synthesise current scientific knowledge on sow and piglet needs and practical experience of existing non-crate farrowing systems, and use economic modelling approaches to characterise the best system prototype(s) based on this information;
2. To consult with expert/ stakeholder groups to refine the prototype(s);
3. To build and develop the prototype(s), testing structural and management innovations considered likely to improve their performance;
4. To scale up the final best system and test this under commercial conditions against conventional farrowing crates;
5. To carry out an economic, environmental and trade analysis of the new system based on commercial performance and costs.

Results and Discussion:

<u>Objective 1:</u> Two scientific review papers have been published: the first detailing the basic biological needs of the sow and piglets at each stage of the pre- and post- farrowing period, and the implications for pen design criteria; and the second reviewing all research and development work on non-crate farrowing accommodation and evaluating the welfare and economic aspects of existing systems. In addition a paper on the economic optimisation modelling has been published.

<u>Objective 2:</u> The project Steering Group representing sponsors, industrial, welfare NGO and academic partners met on 10 occasions to discuss all stages of the project development. In addition there have been ongoing discussions about the progress of the project with different stakeholder groups and site visits (45+), producer talks (21) and popular press articles (10), which have fed into the prototype development. To meet the demand for information, an interim briefing note describing the project objectives, prototype design and preliminary performance indications was made available in February 2010. A further document detailing recommended design criteria and building “tips” was prepared in July 2010. It is emphasised that we consider that the detail of the design is very important for its performance and any deviation carries an element of risk. We encourage anyone wishing to build pens to contact us for a more detailed discussion of key features.

<u>Objective 3:</u> Twelve prototype PigSAFE farrowing pens (Piglet and Sow Alternative Farrowing Environment) were in use for one year at each of the Newcastle and SAC Edinburgh farms to collect experimental data. Overall results from this phase indicated promising performance, with results from the first 152 weaned litters (23% gilt litters) shown in Table 1.

Table 1. Interim performance of PigSAFE prototype pens (for the period 2009-2010)

	Total born (BA+BD)	Total weaned	%Total mortality	%Live-born mortality	%Stillborn mortality
PigSAFE	14.00	10.88	19.06	14.92	5.86
BPEX indoor average	12.28	10.12	17.59	12.30	6.11

Although live-born mortality was higher than the current UK average for indoor farrowing systems, this was against the background of a very high litter size (known to increase mortality levels), and number weaned per

litter was good. Whilst these results were influenced by experimental constraints, they indicated that the system had potential and merited more rigorous commercial evaluation.

A structured 2x2 comparison of key pen design and management features was completed at both sites. At Newcastle, neither degree of nest enclosure/soundproofing nor quantity of nesting substrate supplied had a significant influence on piglet survival, nest building behaviour, maternal responsiveness in a piglet scream test or sow performance. At SAC, the 2x2 structured comparison showed that floor temperature at the time of farrowing, regulated by under-floor heating, had no significant influence on piglet survival. However, total pen size showed effects with higher mortality in the larger pens. Behavioural analysis suggests that the greater mortality was a result of a larger nest area in which the sow could lie down unsupported.

Objective 4: Following completion of the structured comparison, pen modifications required prior to commercial testing were identified based on experience during this work. At the Newcastle site, the major changes related to the redesign of one of the nest walls to facilitate better hygiene management, modifications to doors to improve accessibility, and provision of better piglet creep entrance design and feeding arrangements. At SAC, greater structural modifications were needed in order to reduce the nest size in light of the results previously described. In addition, changes were needed to creep fronts (to facilitate easier nursing by the sows and further protect piglets) and to the dividing wall. Commercial comparison was then made during which farm staff at each site operated both PigSAFE and farrowing crates with minimal experimental constraints, and data were collected over one year on production, labour and resource use. Combined data from the two sites at the end of the project (304 sows, n=164 in Crates n=140 in PigSAFE, approximately 10% gilts) indicate promising results, with no significant performance differences between the crate and PigSAFe systems (Table 2).

Table 2: Performance of PigSAFE pens vs. Farrowing crates, operated under commercial management, to August 2011 with BPEX average and top third farrowing crate data with BPEX average and top third farrowing crate data for comparison.

	Total born (BA+BD)	Total weaned	%Total Mortality	%Live-born mortality	%Stillborn mortality
PigSAFE	12.95	10.73[a]	13.25[b]	9.60[c]	4.11[b]
Farrowing crates	12.80	10.80[a]	11.98[b]	8.98[c]	3.41[b]
BPEX indoor average	12.28	10.12	17.59	12.30	6.11
BPEX indoor top third	13.39	11.18	16.50	10.31	5.60

[a]Adjusted for net fostering; [b]Adjusted for litter size; [c]Adjusted for litter size post fostering

Engagement with industry throughout the project has resulted in construction of two large-scale commercial systems in the UK and Australia, as well as further smaller scale systems, and engagement continues with other interested producers. Requests from industry for consultancy, site visits and on-going production information continue and are considered a crucial aspect of the work that needs to continue beyond the project end-date.

Objective 5: To determine the relative importance of current alternative farrowing systems in the UK pig breeding herd and the potential for uptake of non-crate systems, data were gathered via an on-line survey. Responses represented 20% of the UK indoor breeding herd. When asked what system they would consider when re-building farrowing accommodation, 64% of respondents said they would not change their current design but 27% would consider something different. Of the latter, one third would consider a swing-side/360° farrower-type design, one-third would consider a PigSAFE-type pen and the remaining third were undecided. Overall, the survey showed that the industry needs to reinvest but are cautious about adopting an alternative to the crate.

To analyse the effects on production costs of adopting a non-crate farrowing system, a spreadsheet-based costings model was developed. A linear programming (LP) model was then used to consider various scenarios for uptake. A total of 10 farrowing systems were modelled, including the PigSAFE system and three other systems being considered as alternatives to the farrowing crate. The models allowed for consideration of different scenarios, including levels of piglet mortality, for each system. The results indicate that, with similar animal performance, the costs of pig production using the PigSAFE system would be approximately 3.5% higher when compared to using a standard farrowing crate. This arises because of the greater space requirements and additional engineering in the PigSAFE design. Any improvement in pig performance (e.g. through improved piglet weaning weight or sow rebreeding) would narrow the cost difference. Thus, whilst some UK producers are prepared to consider alternative non-crate systems when replacing their farrowing accommodation, the models suggest that a price premium would be required to ensure financial viability of the new systems.

The final modelling phase analysed the effects of the implementation of the “new” farrowing system on trade and environment using partial equilibrium (PE) modelling approach. The change in animal welfare had a negative, however slight, impact on international trade in pig meat under the PigSAFE scenario compared to baseline scenario. The small positive change in the environmental impacts between baseline and PigSAFE scenario was not found significant.

Project Report to Defra

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:

- the scientific objectives as set out in the contract;
- the extent to which the objectives set out in the contract have been met;
- details of methods used and the results obtained, including statistical analysis (if appropriate);
- a discussion of the results and their reliability;
- the main implications of the findings;
- possible future work; and

Scientific objectives:

1. To review and synthesise current scientific knowledge on sow and piglet needs and practical experience of existing non-crate farrowing systems, and use economic modelling approaches to characterise the best system prototype(s) based on this information;

2. To consult with expert/ stakeholder groups to refine the prototype(s);

3. To build and develop the prototype(s), testing structural and management innovations considered likely to improve their performance;

4. To scale up the final best system and test this under commercial conditions against conventional farrowing crates;

5. To carry out an economic, environmental and trade analysis of the new system based on commercial performance and costs.

Summary of methods, results and conclusions for each objective

Objective 1: April 1st-October 31st 2008

Literature review and synthesis of knowledge: A literature review was undertaken to establish/confirm the biological principles (including ethological understanding) underlying sow-piglet interactions in the perinatal period. From this, a list of biological specifications for non-crate farrowing systems was derived, which included requirements for environmental enrichment for the sow and her litter. This review highlighted gaps in the knowledge which could be used to develop innovation experiments for milestone 3. This review was reported to Defra and a subsequent peer-reviewed manuscript completed (Baxter et al. 2011a - see section 9). A second critical review was undertaken to gather information on all known non-crate farrowing systems (including outdoor systems), to identify the extent to which each system addressed biological specifications and its practical success. A total of 345 items of literature were reviewed, of which 153 items were considered to yield sufficient detail to provide information on different aspects of a range of farrowing systems, including design characteristics and performance data. Initially 30 different farrowing systems were identified, which were then grouped, based on common features, to reduce to 14 systems. An assessment of how well alternative systems satisfy design criteria for meeting animals' biological needs (as determined by the first review) was made by developing a welfare design index (see Figure 1).

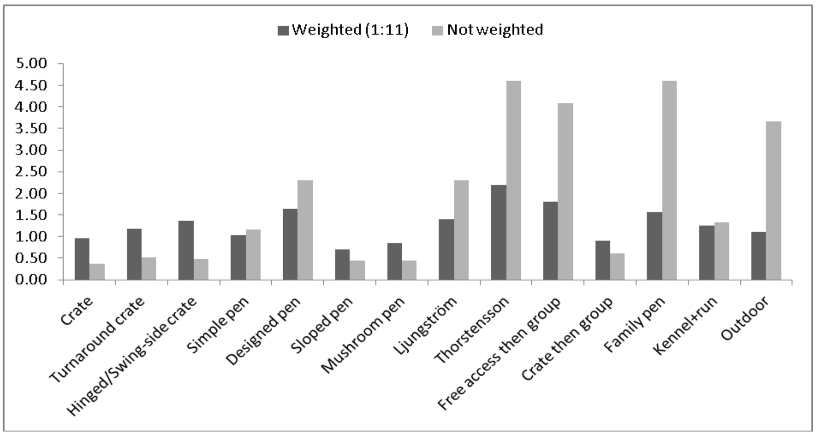

Figure 1: Welfare design scores for each evaluated system, as determined by assessing how well each system meets the biological needs of the animals during the three phases of farrowing: nest-building, parturition and lactation. The differences between weighted scores (piglet criteria multiplied by 11 per litter) and non-weighted scores (sow given equal weighting to litter as a whole) are shown.

Physical and financial performance of these systems was also evaluated and summarised. Throughout this process, the critical review of different systems was hampered by lack of comprehensive data and detailed system descriptions. As a result, in order to assign some standardised estimation of investment costs to each of the 14 systems, farm building experts were consulted. The additional floor space and "furniture" required for the designed pens was reflected in the higher investment cost per sow place compared to simple pens (8.8% higher), crates (17.5% higher) and some modified crates (9.6% higher). From the data that were available, and our critique of systems, it was clear that no one system satisfied the biological needs of both the sow and her piglets (Fig. 1). The "best" indoor alternative was identified as the designed pen (e.g. FAT systems, Werribee farrowing pen, Schmid pen) which provides different areas to fulfil different functions, in addition to showing comparable labour requirements and reasonable investment costs. Information from the review of existing systems provided information for economic modelling approaches (Objective 5) as well as discussion with stakeholders to develop a prototype system (Objective 2). It also resulted in the publication of a peer-reviewed manuscript (Baxter et al. 2012 - see section 9).

Economic (optimisation modelling): The aim was to utilise the information provided by the biologists regarding biological needs and the assessment of different systems to establish acceptable trade-offs between profit and welfare within these alternative systems. Linear programming (LP) was used to examine these trade-offs and optimise the economic performance of different systems, including the conventional crate and the designed pen, when subject to both managerial and animal welfare constraints. Quantitative costs for constraints were derived from the literature, and the potential effects of each welfare component on productivity were assessed by the animal welfare scientists in the Steering Group. Examples of modelled welfare components (inputs) were extra space, substrate and temperature. Results showed that, when using piglet survival rate based on data drawn from the literature and incorporating costs of extra inputs in the model, the crate provided the highest annual net margin. This outcome was expected, mainly because of the lower fixed costs (e.g. investment) and variable costs (e.g. labour) associated with crates. However, by entering improved production functions based on the assumption that certain welfare components would increase productivity (e.g. increasing space improves maternal behaviour thus improving piglet survival), the designed pens benefitted and gained a net margin which was sufficient to overcome the cost advantages of the crate. The methodology and outcomes of this work were published in a peer-reviewed journal (Vosough-Ahmadi et al. 2011 - see section 9).

Conclusions: Information was synthesised and discussions between biologists, economists and engineers resulted in the identification of a system prototype, with potential innovations to test experimentally.

Objective 2: August 1st – October 31st 2008

The project Steering Group, representing sponsors, industrial, welfare NGO and academic partners, met on 10 occasions to discuss project development, with minutes being circulated on each occasion. After the completion of Objective 1, stakeholder discussion was used to review the results and confirm the assumptions and relationships used in the modelling. In addition a SWOT analysis was conducted on prototype system designs as well as consideration of innovative approaches. The prototype pen (Figure 2), hereafter designated the PigSAFE pen (Piglet and Sow Alternative Farrowing Environment), involves a basic nest area, with solid flooring to allow provision of nesting material, and sloping walls to slow sow stand-to-lie posture changes and lower the risk of piglets being trapped and killed. A heated creep area has easy access from the nest. A separate slatted dunging area is bounded by walls with barred panels to adjacent pens, to discourage farrowing outside the nest and allow sow-to-sow visual and oral-nasal contact. A sow feeding crate (solid-sided) is included at one side of the pen, where the sow can be locked in to allow safe inspection or treatment of the piglets, but is not wide enough to allow the sow to be locked in for farrowing. Dynamic elements of the design include (at the SAC site – see later for details) the ability to open up the nest area after a designated amount of time (~ 7 days post-farrowing) to improve hygiene and simulate nest departure. This design and proposed experimental innovations were presented to and subsequently approved by the Steering Group.

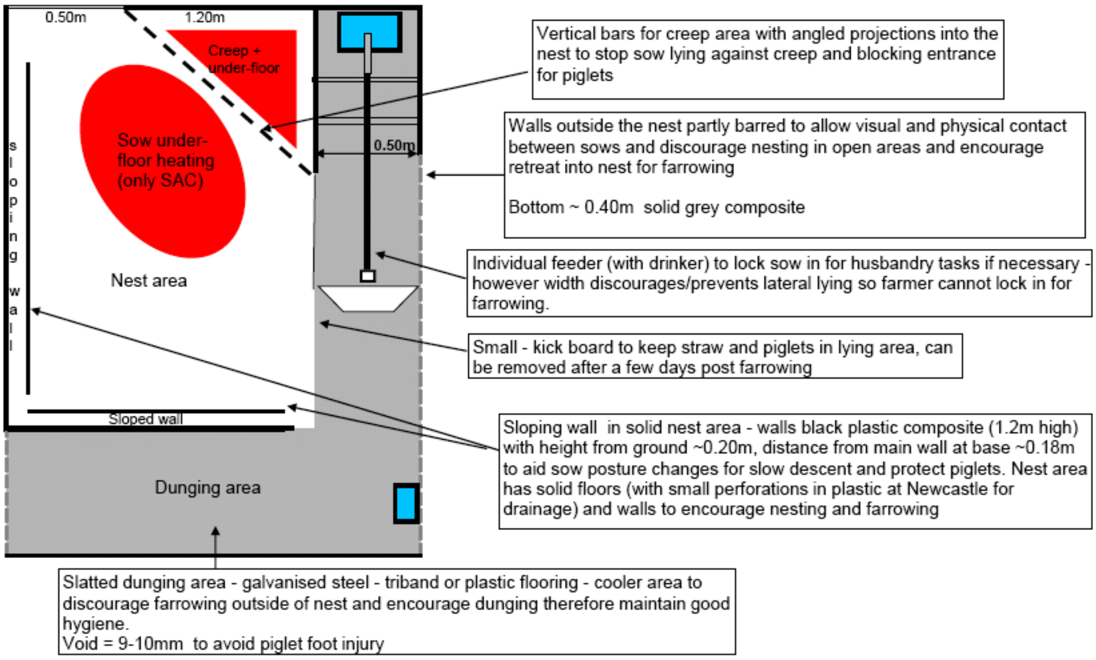

Figure 2: Basic design of the PigSAFE farrowing pen with different areas designed to fulfil different functions.

<u>**Objective 3:** November 1st 2008 – 31st March 2010</u>
After agreeing the prototype design the core system was built at Newcastle and SAC to "model" two potential implementation scenarios and to rapidly de-bug obvious problems. Twelve prototype pens were then monitored in experimental use for one year at both sites.

Experimental design and methodology:
Experiments were designed to test structural and management innovations for achieving biological targets. From the literature review process it was evident that certain important questions remained unanswered:

1. How much space is required to satisfy biological needs of the sow, such as nest-building behaviour?
2. Does nest-site temperature influence the choice of farrowing location and piglet survival?
3. How much substrate is required to satisfy nest-building behaviour?
4. What is the influence of a quiet nest-site on maternal behaviour and piglet survival?

The 2x2 experimental designs saw the effect of space and temperature tested at SAC and the influence of substrate and quiet tested at Newcastle. At SAC, two sizes of pen were tested in this experiment; one measured 9.7m^2 in total (LARGE) (2.2m x 4.4m), with a nest area of approximately 4.0m^2, and one was of the same design but smaller, measuring 7.9m^2 in total (SMALL) (2.2m x 3.6m) with a nest area of approximately 3.3m^2. The aim was to test the influence of space on farrowing location and piglet survival. In addition, the solid nest areas of the pens were fitted with under-floor heating which could be individually controlled. The floor was heated to one of two treatments; HIGH at 30°C and LOW at 20°C (from 48h before until 24h after farrowing), to test the hypothesis that a warmer nest might be more attractive to farrowing sows and improve piglet survival (Figure 3). For nesting, 2kg of straw was maintained by daily replenishment (not cumulative) from day -5 to day +7, and then from day +7 1kg of straw was given daily.

Since SAC was a new build scenario, and thus there was less constraint on space, a dynamic feature of the pen was that the wall dividing the dunging and nesting areas was hinged and could be opened up 7 days post farrowing with the aim to improve hygiene and simulate nest departure. Since there was no existing slurry system, an under-floor scraper system was installed under the dunging passage to allow for solid manure removal. The nest, feeder and creep areas all had solid, concrete flooring. Twelve pens (6 SMALL and 6 LARGE) were built in the same room. At Newcastle, the basic pen design was the same but, as it was a retrospective fit of an existing farrowing house room, there were more constraints on space (overall pen = 2.36m x 3.35m = 7.9m^2). Therefore the dunging passage was narrower (0.95m width x 2.36m length) and the dividing wall could not be swung back (Figure 4). The design was built over an existing slurry system and plastic rather than metal or concrete flooring was used. The nest and creep areas had solid floors, but the plastic solid panels had small perforations to aid drainage of any urine or placental fluids. Four prototype pens occupied one farrowing room, with three rooms (12 pens) in total and the 2x2 treatments were balanced per room. At both sites sawdust-bedded creep areas were heated to 30°C; by an infra-red heat lamp at Newcastle or by floor heating at SAC which reduced after farrowing on a temperature curve.

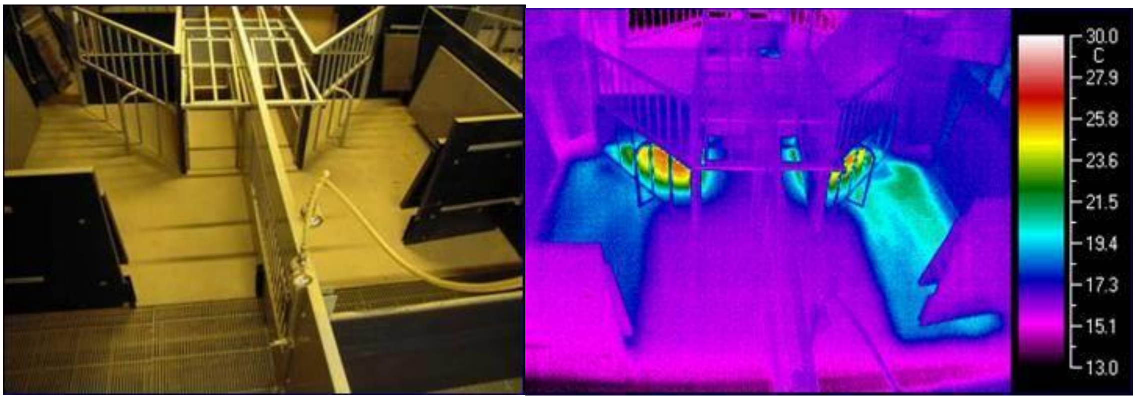

Figure 3: SAC experimental PigSAFE pens showing 2x2 design: LARGE and SMALL pen treatments with LOW (20°C) and HIGH (30°C) under-floor heating treatments.

a)

b)

c)

Figure 4: The Newcastle PigSAFE pen. a) The nest size was similar to SAC's SMALL treatment, with the same basic design features; b) Four pens were fitted in one room and sows entered individual pens through doors in the dunging passage); c) In each room, two pens were provided with sound proofing material and a temporary roof fitted for the QUIET treatment (picture shows dividing walls between pens open in dunging passage).

The Newcastle 2x2 experimental design involved testing a substrate treatment where the minimum amount of substrate was provided to the sows (MIN) vs. a maximum amount (MAX). For MIN 2Kg of long stemmed straw was provided at entry on day -5 and maintained until +2 days after farrowing. This was not cumulative but replenished daily to make sure the sow has access to 2Kg of long-stemmed straw each day until day +2. After +2 days, the minimum treatment continued to receive a nominal amount of straw daily until weaning. The MAX treatment (4Kg) was designed to allow the sow to create a suitable nest by herself. The minimum amount was spread across the lying area and then additional long-stemmed straw was provided to allow further nesting. This was done until +2 days after farrowing, after which the sow and litter were maintained with 2Kg of straw per day until weaning. For the QUIET treatment, two pens per room were fitted with noise suppression material and a sound insulated roof, to test the theory that sows may prefer a quiet nest site and show better responsiveness to the cues of their own piglets in an undisturbed area. Digital recordings of piglet screams were used to test the sound attenuation of insulation material at different sides of the pen. A 10 decibel reduction in noise would reduce acoustical energy by 90% and this would effectively make the noise sound "half" as loud. From initial trials of insulation material, this 90% sound suppression was only achievable when a roof was added to the design as well as sound insulation material added behind the sloped walls in the nest area (see Figure 4). Thus the QUIET pens were fitted with these materials and the CONTROL pens were left unroofed and without sound suppression material.

The intention was to farrow 25 sows per treatment (100 in total) at each site, balancing for parity, previous farrowing environment and previous treatment (as sows were likely to feature at least twice in the experiment over the course of the year). As a result of the large number of parameters to be recorded, technical staff at each site were responsible for implementing the experiments.

Measurements: Pig performance and behavioural data were collected at both sites. Additional production information included daily recordings of labour requirements (i.e. time to undertake tasks) and any problems encountered with the system.

Performance information: Piglet survival was recorded with post-mortem examination confirming cause of death. Pre-farrowing (entry) and post-weaning weight, condition score, back-fat depth measurements, lameness scores and injury scores were recorded from sows. Piglets were weighed at birth, seven, 14, 21 days and at weaning, and injury scores were taken. Sow feed and water intake were recorded. Health records of all animals were maintained daily.

Behavioural information: Video cameras captured continuous data from all pens from day -5 until at least day +2. Of particular interest was where sows chose to farrow, the frequency of posture changes during farrowing, the site of piglet injury or death and how influential substrate treatment was on nest building behaviour. In addition, at the Newcastle site, sow responsiveness was tested in a "piglet distress call" test to further determine the influence of a quiet nest-site on maternal behaviour.

Statistical methodology: The actual number of sows in each treatment across both sites were unbalanced and thus for statistical analysis linear mixed models were fitted to the data. Models allowed sow to be fitted in the random model to account for litter effects and co-variates known to influence performance data (i.e. litter size influences piglet survival) could be fitted as variables in the fixed effects to take account of any variation explained by these data.

Results: Overall results from Objective 3, based on the first 152 weaned litters (23% gilt litters), are shown in Table 3.

Table 3: Interim performance of PigSAFE prototype pens (2009-2010)

	Total born (BA+BD)	Total weaned	%Total mortality	%Live-born mortality	%Stillborn mortality
PigSAFE	14.00	10.88	19.06	14.92	5.86
BPEX indoor average	12.28	10.12	17.59	12.30	6.11

Although live-born mortality was higher than the current UK average for indoor farrowing systems, this was against the background of a very high litter size (known to increase mortality levels), and number weaned per litter was good. Whilst these results were influenced by experimental constraints, they indicated that the system had potential and merited more rigorous commercial evaluation. At both sites the majority of piglet deaths (~50% of deaths) were the result of crushing by the sow. Of the 2290 piglets born alive across both sites, at least 17% experienced crushing of some degree (fatal or non-fatal). Standing-to-lying was the riskiest posture change undertaken by the sow, responsible for 33% of both fatal and non-fatal crushes. The open nest area and the area between the access door and the sloped wall were the riskiest areas in the pen for the piglets at Newcastle and SAC respectively, resulting in 55% and 60% of non-fatal and fatal crushings.

The structured 2x2 comparison of key pen design and management features was completed at both sites by June 2010. At Newcastle neither degree of nest enclosure/soundproofing, nor quantity of nesting substrate supplied, had a significant influence on nest-building behaviour, piglet survival (Live-born mortality, Quiet=14% vs. Control=17%, sem=1.52, P=0.16; Min=17% vs. Max=14%, sem 1.52, P=0.11), maternal responsiveness in a piglet scream test or sow performance. The higher level of straw posed problems for manure management, with significant amounts entering the liquid manure storage channel under the dunging area. At SAC, the 2x2 structured comparison showed that the floor temperature at the time of farrowing, regulated by under-floor heating, had no significant influence on piglet survival (Total mortality, Low=22% vs. High=22% $F_{1,87}$=0.00 P=0.996; Live-born mortality, Low=17% vs. High=18% $F_{1,87}$=0.66 P=0.621). However the amount of space influenced live-born mortality, with significantly more piglets dying when sows were afforded larger farrowing space (Large=21% vs. Small=14% $F_{1,87}$=4.18 P=0.044). Analysis of behavioural data suggests that the nest size is an important factor in piglet survival, with greater mortality in the larger nest space as a result of larger areas in which the sow can lie down unsupported.

For farrowing location analysis the pen was divided into seven areas (L1-L7), with L1 deemed the safest area for the piglets to be born (in the nest, furthest from dunging area and closest to creep) and L7 the least protected (being in the dunging area) (see Table 4). At both sites the majority of sows started farrowing in L1 (68%), with 40% of the remaining piglets being born in this position. Farrowings in the dunging passage were very rare (<2%). Table 4 shows differences in the location of piglet births between the sites.

Table 4: Farrowing location for percentage of all first born piglets and percentage of all piglet births at SAC and at Newcastle.

Farrowing location	SAC		Newcastle	
	First	All	First	All
L1	59	41	80	41
L2	15	22	14	28
L3	13	21	4	23
L4	0	4	0	1
L5	9	8	2	5
L6	1	1	0	0
L7	3	3	0	1

At SAC the temperature treatment had no effect on sow preference to farrow their litter in position L1 (HIGH=35% (±SE=6.1) vs. LOW=47% (±SE=6.7) $F_{1,76}$=1.82 P=0.181), however the small number of sows that farrowed in the dunging area (3%) were from the LOW treatment. Space had no effect on sow preference to farrow the litter in L1 (LARGE=37% (±SE=8.7) vs. SMALL=46% (±SE=7.2) $F_{1,76}$=1.85 P=0.287), however both sows that farrowed outwith the nest area had the SMALL space. In the LARGE space more piglets were farrowed in locations L2 and L3 (L2: LARGE=25% (±SE=5.6) vs. SMALL=18% (±SE=5.1) $F_{1,76}$=0.88 P=0.351; L3: LARGE=28% (±SE=5.6) vs. SMALL=13% (±SE=5.1) $F_{1,76}$=3.99 P=0.049). L2 is a more open area in the LARGE space and additionally it is possible that the significance of L3 with respect to the higher piglet mortality in the LARGE space is that the piglets are further away from the protective creep area. At Newcastle there was no influence of either substrate or quiet treatment on farrowing location, with the most popular locations shown in Table 5.

Conclusions: The prototype design of the PigSAFE pen was successful in promoting sows to farrow in the desired location, irrespective of nest size, floor temperature, amount of substrate or degree of sound proofing. The higher piglet mortality, supported by behavioural data on piglet crushing events, suggest that the larger nest size at SAC was less protective for the piglets and thus a smaller nest would be recommended.

Table 5: Percentage of piglets farrowed in locations 1 - 3 within the quiet and substrate treatments at Newcastle.

	Quiet treatment				Substrate treatment			
Location	Control (%)	Roof (%)	Pooled sem	*P*	Minimum (%)	Maximum (%)	Pooled sem	*P*
L1	42.48	40.21	5.86	0.785	38.40	44.28	5.87	0.480
L2	25.62	30.18	5.17	0.535	24.56	31.25	5.17	0.363
L3	22.98	24.37	4.95	0.843	29.55	17.79	4.95	0.097

Modifications to original prototype: Following completion of the structured comparison at the Newcastle site, some pen modifications were necessary prior to commercial testing. The major changes related to the redesign of one of the nest walls, cutting a pop-hole in the dividing wall which could be opened after 7 days to facilitate better hygiene management, modifications to doors to improve accessibility, and provision of better piglet creep entrance design and feeding arrangements. The Newcastle site also had some problems with the strength of the flooring in the pens, with high traffic areas (i.e. over the kick-board and into the nest) showing too much “give” when the sow was moving. Such weakness can result in loss of confidence by the sows, thus floor tiles and support structures were investigated and some strengthening work undertaken. At SAC, greater structural modifications were needed in order to reduce the nest size of the large pens in light of the results. In addition, changes were needed to creep fronts to facilitate easier nursing by the sows and further protect piglets, and some changes to the dividing wall were made. These changes were agreed by the Steering Group and the protocols were prepared for the commercial comparison phase. The SAC modifications resulted in a delay to the commercial evaluation phase and the subsequent milestones and therefore a request for an extension was made to Defra. This extension was approved by Defra in February 2010 and the project end date delayed until October 2011.

Additional outputs from this phase: In addition to the Steering Group meetings there have been ongoing discussions about the progress of the project with different stakeholder groups and site visits (45+), producer talks (21) and popular press articles (10) (see section 8 for details). To meet the demand for information, an interim briefing note describing the objectives and plans of the project, prototype design and preliminary performance indications was prepared and made available for dissemination in February 2010. In addition, a document detailing our recommended design criteria, details behind the design and building “tips” was prepared for dissemination in July 2010 (see section 8 for further details). These recommendations are based on our experience in designing and running the PigSAFE pen. The information is given in good faith, but it was emphasised that we can accept no responsibility for its adoption, especially if design criteria are modified when building the pens. The recommended design is pictured below (Figure 5).

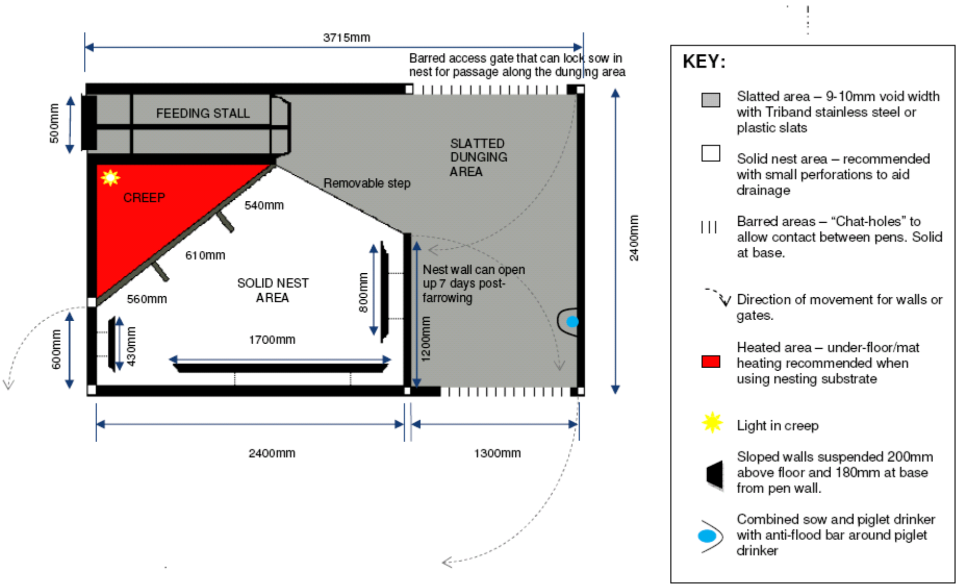

Figure 5: Recommended design and dimensions for building a PigSAFE pen.

Throughout the project it was emphasised that we consider that the detail of the design is very important in its performance and therefore any deviation from the details given in the document of recommended design criteria is done at the producer's own risk. We encouraged, and continue to encourage, anyone wishing to build pens to contact us for a more detailed discussion of key features.

The results from this phase and the proposed design modifications were presented to Defra, who approved progression to the final phases of the project.

Objective 4: April 1st 2010 – September 30th 2011
This objective involved a standardisation of the final prototype system at Newcastle and SAC and conduct of a commercial-scale comparison against conventional farrowing crates. For this phase, farm staff at each site were responsible for operating both PigSAFE and farrowing crates, given minimal experimental constraints. At Newcastle, both systems could be operated simultaneously, with sows within each 3-weekly farrowing batch divided between the two systems. At SAC the all-in all-out nature of having PigSAFE farrowings in one room meant that farrowing batches had to run alternately in each system, separated by 3 weeks. Data were collected on pig performance, labour, feed, water and straw use. Environmental data from within the buildings was automatically recorded.

Results:
Performance: Combined data from the two sites (304 sows, n=164 in Crates n=140 in PigSAFE, approximately 10% gilts) are shown in Table 6 against the BPEX 2010 average and top third data.

Table 6*:* Performance of PigSAFE pens and farrowing crates for the period to August 2011, with BPEX average and top third farrowing crate data for comparison.

	Total born (BA+BD)	Total weaned	%Total mortality	%Live-born mortality	%Stillborn mortality
PigSAFE	12.95	10.73[a]	13.25[b]	9.60[c]	4.11[b]
Farrowing crates	12.80	10.80[a]	11.98[b]	8.98[c]	3.41[b]
BPEX indoor average	12.28	10.12	17.59	12.30	6.11
BPEX indoor top third	13.39	11.18	16.50	10.31	5.60

[a]Adjusted for net fostering; [b]Adjusted for litter size; [c]Adjusted for litter size post fostering

At Newcastle, the PigSAFE system performed very well, with no significant difference compared to crates (Figure 6) and both systems performing better than the BPEX top third farms.

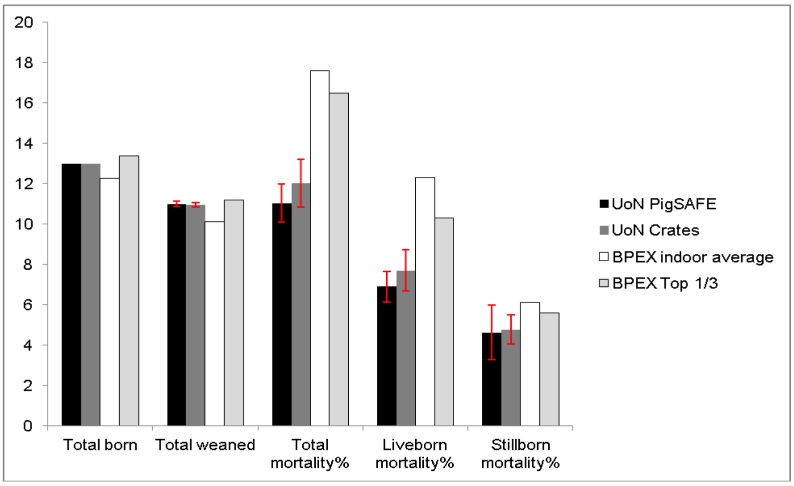

Figure 6: Comparison of pig performance at Newcastle (UoN) in PigSAFE pens (n=83 litters) or farrowing crates (n=78) alongside BPEX indoor average and top third performance for Year 2010. Mortality data are adjusted for net fostering (similar in both systems) and for litter size.

At SAC there were no significant differences between systems, although mortality in the PigSAFE pen was closer to the BPEX indoor average (Figure 7).

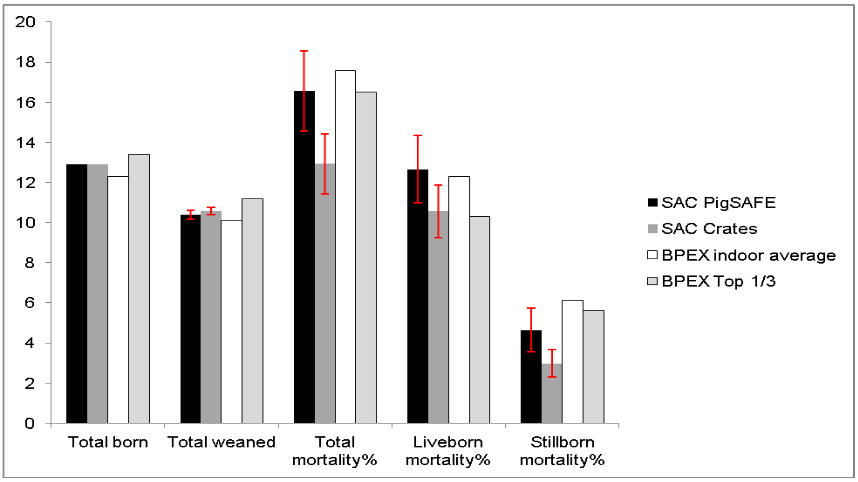

Figure 7: Comparison of pig performance at SAC in PigSAFE pens (n=62) or farrowing crates (n=81) alongside BPEX indoor average and top third performance for the year 2010. Data are adjusted for parity and litter size.

At SAC, pig performance in PigSAFE pens has shown an improvement with every batch farrowed, highlighting that stock-person training is an important aspect when adopting a new system. The farm manager at SAC had previously worked with sows in crates for over 25 years and thus was unfamiliar with loose farrowing and lactating sows. The learning curve is indicative of potential scenarios when implementing a new system on a commercial farm where staff have previously had little or no experience of animals farrowing and lactating loose.

Sow and piglet condition: Body weight (kg) and back-fat depth were measured on sows pre-farrowing and post-weaning and piglets were weighed at weaning. Table 7 shows that although there were no significant differences between housing systems at Newcastle, at the SAC site piglets weaned from PigSAFE pens were significantly heavier than those from crates (average individual weight 8.77kg v. 8.45kg).

Table 7: Influence of farrowing accommodation on sow body condition and piglet weaning weight (adjusted for litter size, weaned litter size and weaning age). For statistical purposes, sites were compared separately.

	Sow condition		
	Weight loss (kg)	Back-fat loss (mm)	Average litter weaned weight (kg)
SAC PigSAFE	27.68	4.45	91.33_a
SAC Farrowing crates	29.71	4.18	87.77_b
UoN PigSAFE	38.81	4.18	78.05
UoN Farrowing crates	38.54	4.28	76.14

Subscripts with different letters indicate figures are significantly different at P<0.05

Feed intake, labour and pen hygiene data: At SAC there was a tendency for sows housed in PigSAFE pens to eat more than those housed in crates (7.27kg v. 6.44kg per sow per day $F_{1,6}$=3.45 P=0.088). At Newcastle there were no significant differences in feed intake between farrowing systems (P=0.621). It is possible that the difference in feed intake is only seen at the SAC site as a result of potentially beneficial effects of the building in which the PigSAFE pens were built. The “new build” scenario implemented at SAC involved a large building shell, with high roof space and thus a more airy environment for the sows. Recordings of time taken to perform daily husbandry routines (i.e. number of minutes of labour per sow per batch) showed that significantly less labour (P=0.043) was needed in PigSAFE pens compared with crates at SAC (Figure 8). These husbandry data were supported by the difference in subjective pen cleanliness scores between the systems at SAC with PigSAFE pens being significantly cleaner than the crates where hygiene scores (1-4 with higher indicative of poorer hygiene) were taken at days 7 and 14 after farrowing (P=0.001 - Figure 9). In comparison, at Newcastle the amount of labour required for PigSAFE pens was less than that for crates, yet the cleanliness of PigSAFE pens was worse than that for the crates as determined by a higher pen hygiene score taken at 7 and 14 days after farrowing (P<0.005).

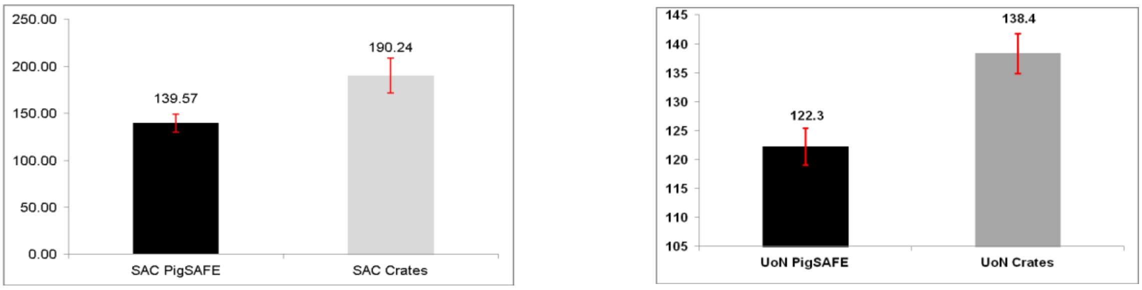

Figure 8: Difference in time taken to perform daily husbandry routines in the different systems at SAC and UoN (minutes of labour per sow per batch).

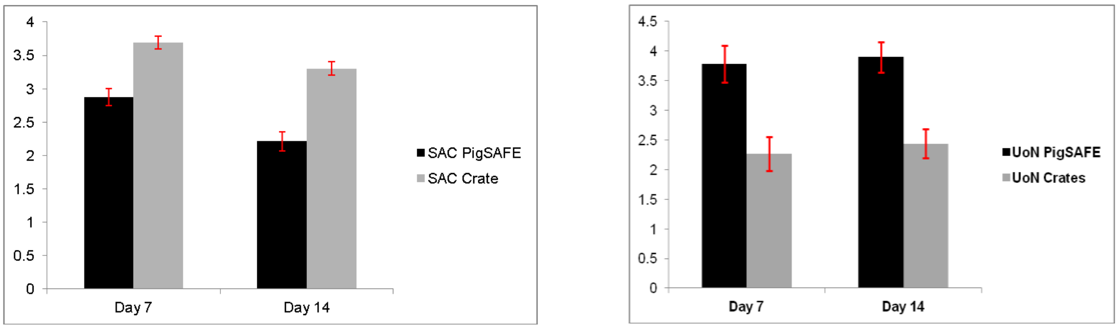

Figure 9: Difference in hygiene scores (1 - 4, a higher score is indicative of poorer hygiene) at day +7 and day +14 after farrowing between PigSAFE and crates at SAC and UoN.

It is likely that these results are farm specific. The SAC farm's conventional crated system is predominantly solid concrete with a metal slat at the rear of the sow, resulting in high daily labour input to clean out. The SAC PigSAFE system benefitted from an under-floor scraper system and large amounts of slats in the dunging passage, facilitating good hygiene and easy management. In addition the SAC PigSAFE system has the room to swing back the wall dividing dunging passage and nesting area – which was done at day +7. This contrasts with lower labour, part-slatted crates at Newcastle. Although Newcastle introduced pop-holes to better aid hygiene in the PigSAFE system, it is likely that swinging the wall back completely and a larger dunging area resulted in the significantly better effect on pen hygiene at the SAC site.

Stock-person feedback: It was noted by the stock-persons at both sites that there was a great deal of individual sow and litter variation regarding cleanliness and maternal behaviour. With nest hygiene being an important factor in labour input and disease control, and maternal behaviour influencing piglet survival and stock-person-sow interaction, this individual variation is worth further investigation. The stock-persons differed at the two sites, with staff at the Newcastle site having previous experience of working with loose outdoor sows, whereas staff at the SAC site required greater time to learn working routines and adapt. This was reflected in sustained improvement in pig performance over time at SAC, however throughout the scale-up phase it was obvious that the SAC pen could benefit from further improvements: only the dunging area has slats and thus the feeder is solid concrete resulting in poorer hygiene and a slip risk as sows often defecate and urinate whilst standing to feed. The solid concrete floor in the nest-site could also benefit from better drainage facilities to aid placental fluid removal. It is thought that the higher stillbirths in the pens at SAC are somewhat attributable to build up of placental fluid at the birth site. In addition, widening the nest by as little as 20mm would result in greater sow comfort whilst suckling. At both SAC and Newcastle the stock-people voiced the need for a better method of locking the piglets into the creep to aid husbandry routines. However, on the whole, the stock-persons at both sites were enthusiastic about the system.

Conclusions: Results from the commercial scale-up phase showed no significant differences in performance between PigSAFE pens and conventional crates within farm. The most promising results from the Newcastle site showed that the PigSAFE system can perform better than the BPEX top third producers. Clearly a key aspect of any new system is the ability and willingness of stockpersons to adapt to a new system and this effect was clearly seen at the SAC site. There is also some indication of benefits in weaning weights and sow feed intake when using PigSAFE pens compared with conventional crates. The SAC site requires further work to optimise the pens. The recommended design criteria (Figure 5) remains the best design as a result of the research.

Commercial implementation: An ambition of this phase was to achieve scaling up to test the PigSAFE system commercially outwith the two experimental farms. Engagement with industry throughout the project has resulted in two large-scale systems operating on commercial farms in the UK and Australia. In addition there are a number of other small-scale systems being run in the UK and there is continued engagement with other interested producers. Requests from industry for consultancy, site visits and on-going production information continue and considered a crucial aspect of the project that should continue beyond the project end-date.

Objective 5: September 1st 2010 – October 31st 2011

The aim of this objective was to carry out an economic, environmental and trade impact evaluation of the new system by

- Determining the relative importance of existing farrowing systems in the UK pig breeding herd.
- Estimating costs of weaner production under existing systems
- Determining the likely uptake of the new system within the UK industry using LP models of representative breeding units and analysis of the effects of implementation of the PigSAFE and additional 'new' farrowing systems on the cost of production.
- Analysing the effects of implementation of the "new" farrowing system on trade and environment using a partial equilibrium (PE) modelling approach.

5.1 Determination of the relative importance of existing farrowing systems

This task was undertaken to collate up to date information on the type and age of existing UK indoor farrowing systems, the time span for renovation of existing accommodation and the viewpoint of producers with respect to upgrading their existing farrowing system to a free farrowing design.

Data collection: A questionnaire was compiled to ask pig producers specific questions about their existing farrowing system and future plans. For wide distribution and accessibility, the questionnaire was uploaded to the website of the "PigWorld" magazine of the National Pig Association (NPA). Here producers could access the survey and add their answers anonymously. The questionnaire was available online for completion from early January to mid-February 2011. In addition, a short questionnaire was sent to six industry specialists to obtain their opinion on what proportion of indoor sows farrowed in a range of given systems, and what the expected lifespan of such systems was.

Results: A total of 45 on-line questionnaires were completed by UK pig producers. Information on the total number of farrowing places was provided by all but one producer and totalled 10,034 farrowing places, which accounts for around 40-50,000 sows, equating to ~ 20% of the UK indoor herd. Of respondents, 96% farrowed sows in farrowing crates, 2% in a modified crate design and 2% in other systems, of which one producer gave details of an arc housing system. Overall, some 67% of producers expected to replace part of their farrowing system over the course of the next 10 years. The full breakdown of results is shown in Table 8. During refurbishment, 22% of respondents expected to have to replace at least some of their existing building shell.

When asked about plans to replace their existing farrowing system, 64% of respondents said they would replace with the same housing design as they currently had, 27% would consider to replace with a different system and 9% were currently unsure about which system to replace with. Of those producers considering replacing their existing system with a different system (27%), 33.3% preferred a fully slatted system that allowed the sow to turn around, such as the 360 farrower, and 33.3% were considering a non-crated pen design such as the PigSAFE system. A further 8.3% were undecided between the crated or free pen systems, 8.3% selected to opt for other designs altogether and 16.7%

were not sure what system they would choose. Finally, 24% of all producers who answered the questionnaire would consider converting a number of farrowing places into a non-crate system as a pilot, whilst the remaining 76% of those surveyed would not.

Table 8: Proportion of their existing farrowing systems producers that expect to replace over the next 10 years

	1-2 years	3-5 years	5-10 years
% of producers surveyed, planning to replace	31	29	44
% of farrowing places accounted for in survey	25	11	11

N.B. A number of producers opted to replace a percentage of their existing system in multiple year options, i.e. spreading the percentage of existing system conversion over several time points.

The survey of industry specialists received a 67% response rate, although one response did not address the questions asked in a form that could be used and was discarded. Answers from the survey of industry specialists differed slightly to those of the on-line questionnaire, with a larger number of non crate systems indicated (Table 9). However, overall the results were not too dissimilar from those found in the producer survey.

Table 9: Opinion of industry specialists regarding existing UK systems (mean and range in responses).

Proportion of UK indoor sows expected to farrow in the following systems	Mean	Range
1. Farrowing crate	89.7	80 - 95
2. Modified crate (eg. swing-sided, 360 Farrower)	5.7	2 - 13
3. Loose pen with some form of protection for piglets	2.5	2 - 3
4. Traditional strawed pen	2.2	1 - 4.5
5. Other (please specify)	0	0

Expected lifespan of the following systems	Mean	Range
1. Farrowing crate	18.3	15 - 20
2. Modified crate (eg. swing-sided, 360 Farrower)	13.7	10 - 16
3. Loose pen with some form of protection for piglets	19.0	17 - 20
4. Traditional strawed pen	23.3	20 - 30
5. Other (please specify)	na	na

Conclusions:

- Crates are the predominant housing systems for indoor farrowing sows, with good agreement between estimates of the proportion of farrowing sows housed in crates from an on-line questionnaire with the opinion of industry experts.
- Over the next ten years, 67% of farrowing systems surveyed will be renewed.
- When replacing their farrowing system, the majority of producers plan to simply renew their existing system; however 27% of producers opting for different systems suggests some awareness of, and interest in, alternative systems.
- Of those interested to change to a different housing system, most interest was expressed in fully slatted systems that allow the sow to turn around and non crate pens, suggesting an increased confidence in the ability of these systems to deliver acceptable financial performance whilst providing for sow welfare and legislative demands.
- A significant number (24%) of producers surveyed said that they would consider converting a proportion of their accommodation for farrowing sows to a welfare friendly system as a pilot.

5.2 Estimation of on farm costs of weaner production in different systems

A spreadsheet model was constructed that estimates the costs of producing pigs in different free farrowing and conventional farrowing systems. The model estimates the cost of production for the dry and farrowing sow phases, and the subsequent post-weaning phase to produce a weaner pig up to 35kg. Results can be expressed per sow or per pig produced.

The systems: A survey of UK sow housing systems (Gloag, 2002), and additional information on alternative farrowing systems currently available, was used to identify systems to model. A total of 10 farrowing (Table 10) and seven dry sow systems were identified (Table 11). For feeding sows, the outdoor and the loose pen indoor system were designated as hand fed only, whereas for all other systems sows could be fed by hand, or automatically dry fed or wet fed. Taking the differing feeding methods into account this created 26 farrowing system and 12 dry sow system combinations.

Table 10: Farrowing systems identified and costed in the model.

Existing Farrowing systems	Floor type	Feeding methods possible
Static farrowing crate	Fully slatted	HF/AF/WF
Static farrowing crate	Part slatted	HF/AF/WF
Static farrowing crate	Solid concrete floor	HF/AF/WF
Swing side crate	Fully slatted	HF/AF/WF
Floating floor (Nooyen)	Fully slatted	HF/AF/WF
Outdoor	Straw bed	HF
Newly emerging farrowing systems		
PigSAFE	Part slatted - Minimal straw	HF/AF/WF
Arc on concrete yard	Straw bed	HF
Danish free pen	Part slatted - Minimal straw	HF/AF/WF
360 farrower	Fully slatted	HF/AF/WF

HF = hand fed, AF = automatic fed, WF = wet fed

Table 11: Dry sow systems identified and costed in the model

Dry sow systems	Floor type	Feeding
Yard	Straw bed	DF
Yard	Straw bed	SF
Yard	Deep straw bed	ESF
Free access stalls	Solid floor straw use	AF/HF
Free access stalls	Slatted floor	AF/HF/WF
Kennelled yard	Solid floor straw use	AF/HF, ¥
Outdoor	Straw bed	AF - Scatter fed

HF = hand fed, AF = automatic fed, WF = automatic wet fed , DF = dump fed, SF = spin feeder, ESF = Electronic sow feeder, ¥ = individual feeder/sow installed

In this report, the cost of producing a weaned pig in a part slatted crate system will be used as a common industry standard and compared to the cost of production when housing sows in a PigSAFE pen, a Danish free farrowing pen or the Midland pig producers 360 farrower; all higher welfare farrowing pens newly emerging on the market. For all farrowing systems, the dry sow component is accounted for by taking a 50/50 weighted cost of housing in an ESF straw yard or kennelled yard.

Data: To populate the model, data were collected from industry sources and supplemented with scientific literature. The farm structure and performance was based on a unit size of 545 sows, similar to the current average UK national herd size (BPEX, 2010). In the absence of large-scale published data on the comparative performance of pigs in the different farrowing systems under commercial conditions, pig performance (e.g. conception rate, numbers born alive, pre-weaning mortality) was initially assumed to be equal in all systems. To populate the model, herd performance parameters were taken from the average technical performance data for UK indoor herds (BPEX, 2010, p48).

Input cost data used included the costs of building construction, level of resource use (labour, power etc.) in operating the various types of buildings and the unit costs of these resources. Building construction and estimated annual repair costs were derived from quotations obtained from a number of UK commercial pig building companies, assuming new build construction costs and inclusive of a building shell. From this, depreciation costs were estimated based on the expected lifespan of the various building types as shown in Table 12. Repair costs as a percentage of the total capital were initially calculated for the crate and dry sow systems from farm data (Farm business survey, 2010; Nix 2010). The same repair factor of 1.4% of capital cost was given to all systems as it was decided the higher capital per sow place would be reflected in higher repair costs for the newer farrowing systems, due to more complex pen designs with pen divisions and the possibility for the sow to move around, which may mean more wear and tear on pen furniture.

Table 12: Building costs of farrowing sow systems

	Farrowing systems			
Element	**Crate**	**PigSAFE**	**360 Farrower**	**Danish**
Capital cost (£/place)	3,170	4,388	3,670	3,804
Annualised capital cost: 20 year lifetime (£ per £1,000 @ 8%)	102	102	102	102
Sow place cost (£/year)	323	448	374	388
Repair cost @ 1.4% capital (£/sow place/yr)	45	61	51	53
Total cost (£/ sow place/yr)	368	509	425	441

Standard unit prices were collated for feedstuffs, labour cost per hour and machinery. Electrical power use was calculated from an average of a range of data collected from UK farms by Farmex Ltd (Reading, UK). Electricity use was estimated for dry sow accommodation based on recommendations from Farmex. Stockperson labour hours for farrowing, dry sow and weaner phases were calculated from industry labour studies for indoor and outdoor pig systems (Webster and Harper, 2008). Along with data from the Newcastle site, bedding use was calculated from information provided in literature (Vieuille et al., 2003; MAFF, 1993). Levels of machinery use for general sow husbandry, slurry and solid manure disposal were estimated. Standard input prices are displayed in Table 13.

Table 13: Standard input prices used in cost modelling

Resource	Description	Unit	Cost /unit (£)
Feed	Lactating sow diet	Kg	0.21
	Creep feed	Kg	0.74
Vet. and Med.	Farrowing sow	Per sow per year	41.78
Machinery	Tractor hour	Hour	14.55
	Slurry disposal	M^3	2.40
	Farm Yard Manure disposal	Tonne	3.20
Bedding	Straw	Tonne	60
Labour	Stockperson	Hour	13.08
Water	Mains water	M^3	1.30
Power¥	Electrical energy	KW/h	0.10

* = For outdoor production: £32.46/sow/year, ¥ = Not used in outdoor production

Results: The cost of producing a weaner pig in the four different farrowing systems on both a per sow and per weaner basis are given in Table 14. These data assume the same pig performance across all indoor farrowing systems. In addition, the effect of two additional scenarios of changes in pre-weaning mortality of live born piglets are shown to illustrate how the cost of production is affected by pig performance and husbandry. Cost of production was lowest in the conventional crate, followed by the 360 farrower and the Danish system with the highest cost of production in the PigSAFE system. Although the increase may seem relatively small for an individual pig (an extra £1.20 per pig, +3.5%), this would result in an increased cost of production for the typical UK herd of 545 sows of approximately £14,500 per annum, assuming sales of just over 12000 finished pigs per annum.

Table 14: Production costs (farrowing and dry sow, £ GB) per sow per year and per 8 kg weaner produced in four different system combinations and at three levels of mortality.

System	Crate	PigSAFE	360 Farrower	Danish
Sow	£ 776.28	£ 803.64	£ 788.43	£ 789.32
Weaner (12% mortality)	£ 34.03	£ 35.23	£ 34.57	£ 34.60
Weaner (15% mortality)	£ 35.23	£ 36.48	£ 35.79	£ 35.83
Weaner (9% mortality)	£ 32.91	£ 34.07	£ 33.34	£ 33.46

A breakdown of the variable costs of running the farrowing phase of each system are given in Figure 10.

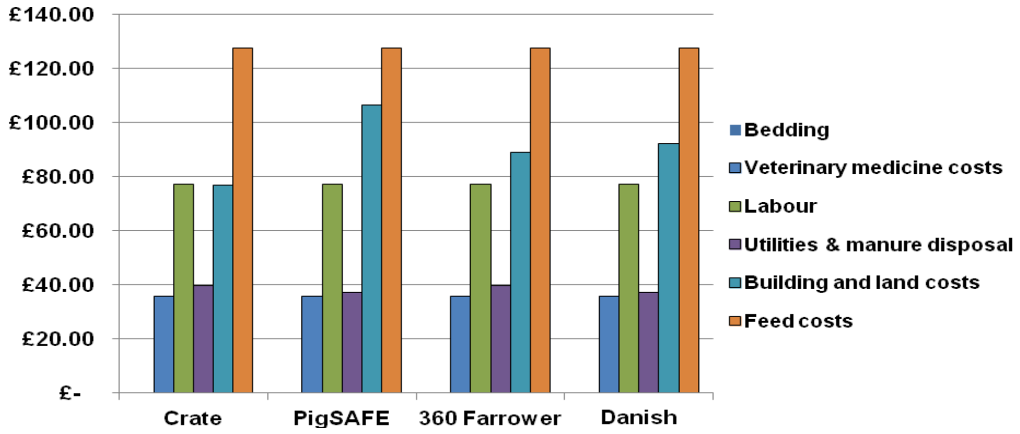

Figure 10: Variable running costs of the farrowing sow phase (£/sow/year) in different systems

Figures 10 demonstrates that building costs (including depreciation, maintenance of equipment) are largely responsible for the difference in cost of production between the systems when using standard pig performance. This reflects the cost of providing the additional space for the alternative systems (considerable in the PigSAFE pen), the cost of the internal pen structures for the various farrowing pen designs, and the increased maintenance cost that will accompany some systems due to the materials used and pen design. Labour costs are similar across systems because, in practice, with a well managed system there appears to be little difference in the labour required. The PigSAFE and the Danish free farrowing pen have some bedding costs. However, given the relatively small amount of straw used (2kg/litter for PigSAFE, up to 1kg/litter for Danish pen), bedding costs are very small at £0.27 and £0.14 per sow per year respectively. Electrical energy costs differ between the farrowing systems due to heat lamp usage, which accounts for a large proportion of energy usage in farrowing systems. In crated systems it is commonplace to have two heated areas (creep area and immediately behind the sow) operating before and shortly after the sow farrows. The PigSAFE and Danish systems will only accommodate one heat lamp, and thus energy costs are lower. Instead, for these free pen systems, any bedding offered can provide some degree of insulation from the floor to newborn piglets.

Conclusions: The cost of production for the farrowing phase, assuming no difference in sow and piglet performance for the different indoor systems, ranked the systems in the order of least to most expensive: conventional crate, 360 farrower, Danish free pen system, PigSAFE system, with a difference of £1.20 per weaner between the cheapest and most expensive indoor system (at 12% live-born mortality). This increased cost of production for indoor free-farrowing systems is mainly a result of increased capital costs: an increased cost of internal pen structures arising from more complex designs and, in some cases, a greater space allowance for each sow place. Changes in mortality will greatly influence the ability of free-farrowing systems to be sustainable.

5.3 LP modelling of representative pig breeding units

A suite of LP models was developed to estimate the costs of production under conventional and alternative farrowing systems, and to test the conditions under which producers might adopt the new farrowing systems. The alternative farrowing systems considered were the PigSAFE system, the 360 Farrower and the Danish free farrowing design. A base model was constructed to simulate a typical UK breeder/finisher unit of 540 sows. Larger (1000-sow) and smaller (200-sow) units were also considered. In each case the new farrowing systems were tested against the conventional farrowing crate-based system and production cost differences calculated. To evaluate the sensitivity of the results to variations in costs, resource use and animal performance input data were changed and the models re-run. Table 15 shows the physical characteristics of the base representative pig unit model.

Table 15: Base model unit characteristics

Unit	Number
Breeding sows	540
Staff (FT equivalent)	4.5
Farrowing places	120
Weaner places	1,200
Finisher places	3,600

Data: The main data used in the construction of the models were derived from the work under Task 5.2. These related to the use, in each phase of each system, of physical resources such as labour and building space (Table 16), costs of production in each phase (Table 17), and building costs for each of the farrowing systems (Table 12). Common levels of animal performance were assumed initially across the various systems. These were: 2.25 litters per sow per year and 10 pigs weaned per litter. Similarly, a common dry -sow system was assumed and its costs calculated as a weighted average of the two most prevalent systems, namely kennels with individual feeders and straw yards with ESF.

Table 16: Building space use and labour requirement at each stage of production

Phase	Pig space use (annual proportion of a place)	Labour (hours per animal)
Dry sows	0.78/year	4.7
Farrowing sows	0.1/farrowing	2.6
Weaners	0.1	0.32
Grower/finishers	0.3	0.08

Table 17: Production costs in each phase (£/animal)

Phase	System	Cost £/animal
Dry sow	Weighted Kennels – Yards	£357[1]
Farrowing sow	Crate	£95[2]
	PigSAFE	£95[2]
	360 Farrower	£95[2]
	Danish	£94[2]
Weaner		£17.24[3]
Grower/finisher		£54.00[3]

1. Dry sow costs are annual total costs excluding labour and weighted 50/50 for the two systems.
2. Farrowing sow costs are per farrowing and exclude building and labour costs.
3. Weaner and finisher costs are per pig excluding labour.

Model runs: The base models were run using the farrowing system data described in Table 12. The models were then re-run to determine the effects of variations in some of the principal cost and performance parameters on the cost of production (Table 18).

Table 18: Variations applied to base model

Parameter	System	Base model	Variation	Value
Building cost	PigSAFE	£509/place	-10%	£458/place
Numbers weaned	PigSAFE	10 pigs/litter	-5%	9.5 pigs/litter
			-10%	9.0 pigs/litter
Building renovation	PigSAFE	£509/place		£377/place
	Farrowing crate	£368/place		£218/place
Weaning weight	PigSAFE	7kglwt	+ 0.3kglwt	7.3kglwt

Results: The results were expressed as cost of pigmeat production in pence per kg carcass weight (p/kg cwt). The base model, using conventional crates, showed a production cost of 145.0p/kg cwt and when using the PigSAFE system this rose to 147.3p/kg cwt, a difference of 2.3p, or 1.6% (Table 19). If numbers of piglets weaned from the PigSAFE system were reduced by 5% (to 9.5 pigs) the cost difference rose sharply to 4.7p/kg cwt, and when reduced by 10%, the cost difference rose to 7.7p/kg cwt or 5.3%. When construction costs of PigSAFE pens were reduced by 10%, the production cost difference narrowed to 1.5p/kg cwt. Similarly, if farrowing buildings were changed by renovation rather than new-build, the cost difference between PigSAFE and conventional crates was reduced to 1.8p/kg cwt. When improved weaning weights were assumed for the PigSAFE system (additional 0.3 kg) this resulted in a reduction of 1.0 p/kg cwt on the basic PigSAFE system, and a consequent production cost of 1.3p/kg cwt over the conventional crate system (Table 19).

Table 19: Effects of variations on production costs

Model run	PigSAFE cost (p/kgcwt)	Difference compared to production cost in a crate (145.0p/kgcwt)	
		p/kgcwt	*%*
Base	147.3	2.3	1.6
Reduced numbers	152.7	7.7 (-1 pig)	5.3
weaned (by 10 or 5%)	149.7	4.7 (-0.5 pig)	3.2
Reduced building cost (10% reduction)	146.5	1.5	1.0
Renovated buildings	145.3	1.8*	1.2
Higher weaning weight (+0.3 kg)	146.3	1.3	0.9

* Renovated crate system cost = 143.5p/kgcwt.

Use of the alternative farrowing systems (the 360 Farrower and the Danish free farrowing systems) showed lower cost increases as a result of their lower building capital costs. The 360 Farrower gave the lowest cost at 1.1p/kg cwt above conventional crates, with the Danish system 1.5p/kg cwt above the crate system. The effect of scale on the structure and level of production costs was examined. There is evidence that larger scale units can achieve lower labour costs, between 15 – 20% per animal, and lower building costs through construction of larger units in each production phase. The evidence for differences in physical performance is mixed, with some survey data showing better performance in smaller units. As far as this study is concerned, the calculations do not suggest that scale would differentially affect the costs of production under the various farrowing systems and therefore is unlikely to affect the decision to adopt a particular non-crate system beyond those factors analysed in the base representative model.

Conditions for adoption of the PigSAFE system:

The results above show differences in production costs between conventional crates and the PigSAFE system under various financial and physical conditions. The results could be turned around to show the conditions under which adoption of PigSAFE pens would be cost neutral. The first of these would simply be the receipt of a premium of 2.3p/kgcwt – to cover the additional basic cost. Similarly, if the annual building costs of the PigSAFE system matched those of the conventional crate, a considerable reduction of some 28% while performance remained constant, the change would be cost neutral. In terms of pig performance, the re-runs of the models showed that the PigSAFE system would be cost neutral if it resulted in 0.55 more pigs weaned per litter, or if sows were bred 2.56 times per year (a biological impossibility under current conditions of weaning age). Similarly, a higher weaning weight, by approximately 0.7 kg, would also eliminate the cost of production penalty. Clearly, some of these factors alone are not practicable, but combinations of more realistic changes such as a price premium, coupled with higher weaning weights, might be more feasible.

Conclusions:

This analysis of the costs of production under alternative farrowing systems suggests that there are two principal factors which affect these: capital costs of construction and animal performance. Capital costs of construction ranged from £3,170/sow place in the case of conventional crates, up to £4,388/ sow place for the PigSAFE system. This difference resulted in a production cost differential of 2.33p/kg cwt over the lifetime of the facilities. This cost penalty would be further compounded if there were poorer animal physical performance, with a loss of an additional 0.5 pigs weaned per litter leading to a rise in production costs resulting in a difference of 4.7p/kg cwt. Similarly, improved performance in the alternative system could narrow the gap, with an extra 0.3 kg lwt at weaning saving 1.0 p/kg cwt in total production costs. This study has focused on production costs and not profitability. Clearly the other factor in the profit calculation is price received for pigmeat produced under the various systems. Price would depend on the details of any contract and the grading of pigs produced, as well as any premium accorded to the different systems under which the animals are produced. While not explicitly considered here this, and any change in housing regulations, would be important factors which could affect the level of uptake of alternative systems.

5.4 Assessment of the effects on trade and environment using PE modelling

Method:
The model simulates the effects of animal welfare changes on the pig production, trade and environment in the United Kingdom. The model has three modules, 'production and trade', 'environment' and 'animal welfare'. The 'production and trade' part of the model includes equations for the pig meat domestic market and trade and also equations for the pig movements (*i.e*., pig stocks, crop of piglets, slaughtering, and losses through death). The demand side of the model includes the equation for the per-capita consumption of pig meat. The supply side of the model includes the equations estimating the number of slaughtered pigs and the average carcass weight to obtain the supply of pig meat and also the equations describing the pig movements to obtain the supply of pigs. The trade side of the model includes equations for imports and exports of both, pig meat and pigs. We close the production/trade part of the model with the equations for the balances on the pigs and pig meat markets under the assumption that the stock evolution is adjusted to offset any excess of supply or demand. The model reaches equilibrium between total demand (*i.e*., domestic consumption plus exports plus stocks carried over to the next period) and total supply (domestic supply plus imports plus stocks carried over from the previous period) with domestic prices clearing the market. The model is recursive dynamic and is estimated by ordinary least squares.

As regards the environmental module of the models, we associate the pollution to the use of production inputs and link the use of nitrogen inputs (e.g., nitrogenous fertilisers, manure) to nitrogen loss through leaching/runoff into groundwater (nitrates) and greenhouse gases (emissions of nitrous oxide and methane). Within the environmental module of the model, we first model the use of nitrogen per hectare based on the conditional demand for the crops included in the pig feed rations. Then we estimate the amount of nitrogen loss through leaching/runoff into groundwater (nitrates) based on the nitrogen balance. Finally, the equation estimating the greenhouse gases emissions (methane and nitrous oxide) is based on the nitrogen use and number of pigs.

As regards the link to the 'production and trade' module, the impact of animal welfare issues (*e.g*., the slightly higher costs of higher welfare in the PigSAFE system as compared to the crate system) is estimated through the pig production equations (*i.e*., those that reflect the evolution of the livestock and slaughtering) in the 'production and trade' module. As regards the link to the environmental module, the animal welfare element affects the environment indirectly through production (*e.g*., changes in manure quantities). The effect of higher animal welfare in the model can be explained through Figure 11. Since about nine per cent of farms adopt the higher animal welfare non-crate system and these have higher marginal costs, the new aggregated supply curve has also higher marginal costs. These can be seen in the figure as a movement of the supply curve to the left, reducing the amount of domestic production of pig meat available. Note that an assumption that is important to reach this result is that consumers do not differentiate between the two types of meat production. Since the domestic price is equal to the EU price expressed in domestic currency, the consumption is not affected and the supply is now covered by higher imports.

We considered two scenarios representing crate system case (baseline) and PigSAFE case (alternative scenario) and compared the impacts on trade and environment between the two scenarios. The simulation horizon covered the period 2011-2020.

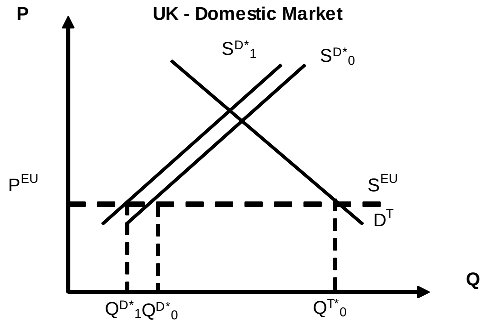

Figure 11: Theoretical representation of the UK pig meat market

Results: As shown in Figure 12, the change in animal welfare has a negative, however slight, impact on international trade in pig meat under the PigSAFE scenario compared to baseline scenario (the trade deficit on pig meat deteriorates gradually to reach 18 thousand tonnes in 2020). The small positive change in the environmental impacts between baseline and PigSAFE scenario was not found significant.

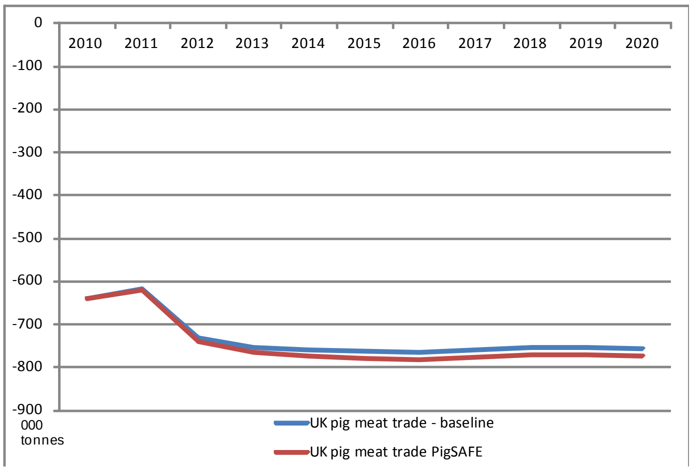

Figure 12: Trade impacts of higher welfare

Future work:
The variation between sows seen in the current project, and results from the previous GENOMUM project (LS3103) funded by Defra, indicate that understanding the genetic and developmental influences giving rise to variation between sows in their response to a loose farrowing environment will be important to the successful adoption of a non-crate system. One aspect showing large variation between sows is the maintenance of nest hygiene, which has major implications for labour requirement in the system – an element highlighted by producers as being a major factor in decision to adopt.

There is a need for monitoring of the commercial performance of the PigSAFE, and other free-farrowing systems, under a range of different commercial farm conditions to assess robustness and analysis of the key factors influencing success of commercial adoption.

Knowledge transfer activities:
There have been over 45 visits to the two sites over the course of the project, with continued interest resulting in further requests. Producers and producer organisations represent 50% of these visits. In addition to the visits, there have been many requests for the interim results and recommended design criteria documents.

Knowledge Transfer publications:

The PigSAFE project: developing an alternative to the farrowing crate. Interim briefing note - February 2010. 5pp.
Recommended dimensions and details for building PigSAFE pens (November 2010). 8pp

Presentations to Industry Meetings: The project has been discussed in presentations given at 21 Pig Discussion Groups (organised by BPEX, NPA and independents):
NPA – Devon 1/4/2009, Dorset 2/4/2009
BPEX – Wiltshire 10/6/2009, Gloucestershire 17/11/2009 and 4/4/2011, Essex 18/11/2009, Lincolnshire 2/2/2010, Shropshire 3/2/2010, Suffolk 3/3/2010, South Yorkshire 25/3/2010, Midlands 30/3/2010, North Yorkshire 20/4/2010 , County Durham 21/4/2010 , East Yorkshire 27/4/2010, Norfolk 18/11/2010, Yorkshire 4/2/2011,
Independent – Lancashire 14/10/2009, Aberdeenshire 27/10/2009
VION – Belfast 27/9/2011 x2
SAC –- Pig industry KT day – 13/10/2010

Press reports:
Knowledge Scotland Initiative – filmed 22/4/2009 – on-going activity, shown regularly
QE Press release – 10/7/2009
The PigSite -New Research Looks at Farrowing Crate Alternatives 10/7/2009
Farmer's Weekly - Research looks at farrowing crate alternatives 20/7/2009
Better Pork – EyeOnEurope: A million dollars for free farrowing December 2009
Pig World – Loose-farrowing March 2010
Pig World – Freedom performance challenges crates May 2010
BPEX Industry update
Weekly Tribune – Welfare must be free from fashion's whim 31/1/11
Pig World – Producers remain sceptical about freedom farrowing 7/2/11
Yorkshire Post – Pens could change face of industry 5/9/2011

References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

Published peer-reviewed articles:

Baxter,E.M., Lawrence,A.B. & Edwards,S.A. 2011. Alternative farrowing systems: design criteria for farrowing systems based on the biological needs of sows and piglets. Animal, 5**,** 580-600. http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=8130219
Baxter,E.M., Lawrence,A.B. & Edwards,S.A. 2012. Alternative farrowing accommodation: welfare and economic aspects of existing farrowing and lactation systems for pigs. Animal, 6, 96-117. http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=8351199
Vosough Ahmadi,B., Stott,A.W., Baxter,E.M., Lawrence,A.B. & Edwards,S.A. 2011. Animal welfare and economic optimisation of farrowing systems. Animal Welfare, 20**,** 57-67. http://www.ufaw.org.uk/documents/vosough.pdf

In preparation for peer-review (these papers are already in draft, further papers based on the conference presentations below will follow):

Baxter,E.M. et al. The PigSAFE pen design - derivation, principles and practicalities.
Cain,P.J., Seddon, Y.M, Guy, J.H. and Edwards, S.A. Estimating the impact of the adoption of non-crate sow farrowing systems in the UK. International Journal of Farm Management.
Guy,J.H., Cain,P., Baxter,E.M., Seddon,Y. & Edwards,S.A. Economic evaluation of high welfare indoor farrowing systems for pigs. Animal Welfare.
Toma, L., Stott, A., Baxter, E.M, Lawrence, A.B., Edwards, S.A. Trade implications of higher welfare. The PigSAFE case study. Animal Welfare.

Conference proceedings:

Baxter,E.M., Lawrence,A.B. & Edwards,S.A. 2010. The Pigsafe pen design - derivation, principles and practicalities. In: Alternative Farrowing Systems – identifying the gaps in knowledge. Animal Welfare Science Centre. Melbourne, Australia.

Edwards,S.A. Baxter,E.M., & Lawrence,A.B. 2010. Commercial Pigsafe performance to date and how these fit in the UK/EU industry context. In: Alternative Farrowing Systems – identifying the gaps in knowledge. Animal Welfare Science Centre. Melbourne, Australia.

Vosough Ahmadi,B., Stott,A.W., Baxter,E.M., Lawrence,A.B. & Edwards,S.A. 2009. Animal welfare and economic optimisation of farrowing systems. In: Knowing Animals congress. ASG Veehouderij WUR , Florence.

Baxter,E.M., Adeleye,O.O., Jack, M., Ison,S. & Edwards,S.A. 2011. The influence of space and temperature on sow farrowing location and piglet survival in an indoor free-farrowing system. Manipulating Pig Production XIII. Proceedings of the Australasian Pig Science Association's biennial conference. Adelaide, Australia. p.239

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Guy,J.H., Cain,P., Baxter,E.M., Seddon,Y. & Edwards,S.A. 2011. Economic evaluation of high welfare indoor farrowing systems for pigs. In: Making animal welfare improvements: economic and other incentives and constraints, UFAW's International Animal Welfare Symposium, Portsmouth, UK.

Edwards SA, Brett M, Seddon YM, Ross D, Baxter EM. 2012. Evaluation of nest design and nesting substrate options for the PigSAFE free farrowing pen. Proceedings British Society of Animal Science, submitted.

Edwards SA, Brett M, Ison S, Jack M, Seddon YM, Baxter EM. 2012. Design principles and practical evaluation of the PigSAFE free farrowing pen. Proceedings Proc 4th European Symposium on Porcine Health Management, Ghent, Belgium, submitted