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Alternative farrowing accommodation: welfare and economic aspects of existing farrowing and lactation systems for pigs

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There is growing societal pressure, expressed through government legislation and consumers' purchasing choices, to abolish livestock systems considered detrimental to farm animal welfare. Such systems include farrowing crates, which are behaviourally and physically restrictive for sows. Therefore, identifying less restrictive farrowing systems for commercial implementation has become an important focus of pig research. Despite numerous attempts to develop indoor alternatives to crates, there is as yet no universal acceptance of such systems at the commercial level. The primary concern is piglet survival, because often favourable figures are reported at the experimental level, but not replicated in commercial evaluation. Alternative farrowing systems should equal or surpass survival levels in conventional systems and perform consistently across a range of farm circumstances for widespread commercial implementation. In addition, it is important that alternatives consider ease of management, operator safety and economic sustainability. Utilising a large database of literature, 12 existing alternative indoor systems were identified and compared against each other, conventional crates and outdoor systems. An assessment of how well alternative systems satisfy the design criteria for meeting animals' biological needs was carried out by developing a welfare design index (WDI). The physical and financial performance of these systems was also evaluated and summarised. The derived WDI yielded values of 0.95 for conventional crates, with higher scores for commercial outdoor systems of 1.10 and indoor group farrowing or multi-suckling systems (e.g. Thorstensson = 2.20). However, the high total piglet mortality (23.7% ± s.e. 2.26) in indoor group systems compared with conventional crates (18.3% ± s.e. 0.63) and outdoor systems (17.0% ± s.e. 2.05), together with the added capital cost (92% more than conventional crates, 249% more than commercial outdoor huts), mainly as a result of extra building space provided per animal, question their feasibility to deliver from an economic perspective. Designed pen systems offered the best compromise, scoring 1.64 from the WDI, with a total piglet mortality of 16.6% (±s.e. 0.88) and capital costs and labour input more comparable to farrowing crates (17.5% more than crates). The critical review of different systems was hampered by the lack of comprehensive data and detailed system descriptions. When attempting to assess welfare and economic attributes of systems, there are certain caveats that require discussion, in particular weighting of the contribution of different design attributes to pig welfare, the relative importance of the sow and her piglets and the many potential confounding factors that arise. Also, when judging any system, it must be emphasised that the maternal characteristics of sows and the quality of stockpersonship will be integral to its success.

Keywords: pig, farrowing, lactation, housing, welfare, performance, economics

Implications

With increasing pressure to abolish the farrowing crate, there is a need to develop a suitable farrowing and lactation system that optimises both animal welfare and commercial performance. This paper attempts to evaluate existing alternative systems, to determine their suitability for commercial adoption and to highlight their strengths and weaknesses to inform further system developments.

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Introduction

Societal opinion, expressed through consumer demand and government legislation, is increasingly influencing practices in the pig industry (Barnett *et al.*, 2001; Bornett *et al.*, 2003; Edwards, 2005). Consumer attitudes towards farm animal welfare differ widely from country to country and are multidimensional, involving such issues as the way in which animals are treated in production and how animal welfare affects food safety and quality (Nocella *et al.*, 2010). Reduction of freedom of movement for the animal, and therefore how much space it is afforded, is a significant point of concern for the consumer (Miele and Parisi, 2001). Within the pig industry, the main issues relating to space are the physically and behaviourally restrictive systems in which sows are kept during gestation, farrowing and lactation (gestation stalls and farrowing crates). In several countries, government legislation has addressed restriction during gestation by unilaterally implementing bans on sow stall use (e.g. Switzerland, Sweden, Norway and the United Kingdom). The European Union (EU)-wide ban (with an exception allowing restraint in stalls until 4 weeks after mating) comes into force in 2013 (Council of Europe, EU Directive 2001/88/EC), with New Zealand and Australia implementing bans in 2015 (NAWAC, 2010) and 2017 (PISC, 2008), respectively, and a number of US states also voting for this policy. One of the major concerns still to be addressed is housing for the farrowing and lactating sow, as the majority of sows continue to be kept in farrowing crates (70% in the United Kingdom – British Pig Executive (BPEX), 2004; 95% in the EU and 83% in the United States – Johnson and Marchant-Forde, 2009) and there is growing societal pressure to abolish such systems. 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 that facilitate efficient labour routines and safeguard the operator. Invariably, such needs conflict with those of the farrowing sow, resulting currently in a predominant system where welfare of the sow is compromised. This compromise is evidenced by research demonstrating that sows kept in crated compared with loose accommodation show heart rate and stress hormone responses, and negative or abnormal behaviours, indicative of an impaired welfare state (Lawrence *et al*., 1994; Jarvis *et al*., 2002; Damm *et al*., 2003).

The commercial outdoor farrowing environment, which often comprises individual farrowing paddocks with farrowing arks or specially designed A-frame huts (e.g. United Kingdom commercial system – Baxter *et al*., 2009; United States – McGlone and Hicks, 2000), represents a system in which it would appear that the needs of all the main stakeholders (sow, piglets and producer) can be more balanced; national herd recording results for pre-weaning and total piglet mortality (stillborn + live-born mortality) in the United Kingdom over the last 9 years reveal that consistently competitive levels of piglet survival are being maintained (total mortality = 16.2% outdoor *v.* 19.1% indoor – Meat and Livestock Commission/BPEX 2000–2009). This is being achieved with relatively low capital and running costs (SAC, 2008), while allowing the sow freedom to satisfy behavioural needs, such as the ability to perform nest-building behaviour, an innate behavioural pattern whose restriction results in stress hormone responses and an increase in negative maternal behaviours (Lawrence *et al*., 1994; Jarvis *et al*., 1997). Given that well-managed outdoor production has the potential to satisfy the biological needs of both mother and offspring, particularly by providing an appropriate environment in which to perform species-specific behavioural patterns, it could be labelled as the gold standard for facilitating high welfare, while being economically efficient. However, there are certain challenges that face both outdoor producer and animal (Edwards and Zanella, 1996) including environmental protection, biosecurity (Callaway *et al*., 2005) and reduction in control over animals compared with indoor systems. Moreover, it can only operate effectively in regions with suitable climate and soil type, which will limit its widespread application in all countries. Therefore, more research is needed to investigate indoor alternatives that can achieve optimum animal welfare with greater managerial and environmental control than that available outdoors.

Various aspects of non-confined indoor farrowing systems have been reviewed previously (Arey, 1997; Edwards and Fraser, 1997; Johnson and Marchant-Forde, 2009) and useful summaries of the performance of these systems show a common concern regarding the variability in pre-weaning survival; the total mortality has ranged from encouraging levels of 9% (e.g. Ottawa crate: Fraser *et al*., 1988) to high levels of 30% (e.g. Free crate and pen systems: Marchant *et al*., 2000). Inconsistent delivery of favourable production figures when moving from an experimental to a commercial evaluation is often cited as the reason for the limited uptake of alternative systems to the farrowing crate (for a review, see Edwards and Fraser, 1997). However, more data are now available from countries where the use of the farrowing crate has been banned (e.g. Switzerland – Weber *et al*., 2007 and 2009; Norway – Andersen *et al*., 2007) for several years, with the exception that a crate can be used for one week *post-partum* for aggressive sows. In Norway, data from 39 herds with loose-housed sows in individual pens showed an average live-born mortality figure of 15.2%, ranging from 5% to 24% (Andersen *et al*., 2007). Data from 99 farms in Switzerland where sows were kept loose for farrowing showed an average live-born mortality rate of 11.8% (Weber *et al*., 2009). The ban in Switzerland has provided an opportunity to collect a large amount of comparative data from systems run at a commercial level in that country. In an earlier piece of work by Weber *et al*. (2007), they demonstrated from an extensive data set (655 farms comprising 63 661 litters) that piglet losses in loose farrowing pens were no greater than in farrowing crates (total mortality (stillbirths + live-born deaths): loose = 17.2% from 18 824 litters and crates = 18.1% from 44 837 litters). Other studies with sufficient sample size to test for meaningful differences between systems have also demonstrated comparable piglet survival figures (e.g. total mortality: loose (Werribee Farrowing Pens) = 21.0% from 66 litters and crates = 24.3% from 80 litters – Cronin *et al*., 2000; 19.1% live-born mortality with no significant difference between crates and pens across 87 litters – Pedersen *et al*., 2011). Despite this evidence, universal acceptance and commercial adoption of non-crate systems has not occurred and it is important to evaluate these systems to determine how well they meet the needs not only of the animals but also of the producer. In particular, when developing new farrowing systems, it is important to maintain the advantages that led to the introduction of the contentious farrowing crate (i.e. decreased over-lying of piglets, ease of management and animal care – Edwards, 2002) and to address both sow and piglet requirements for optimal welfare.

Research into alternative farrowing accommodation over many years has resulted in the development of a number of different systems. The objectives of this paper are to evaluate how well these farrowing systems meet the biological needs of the sow and her piglets, by assessing how well they conform to the design criteria to meet the needs synthesised in a previous review (Baxter *et al*., 2011a). Furthermore, the physical and financial performances of these systems are summarised to present a balanced evaluation of alternative farrowing accommodation.

Methodology

Defining farrowing and lactation systems for evaluation
A database of literature was compiled to evaluate existing systems. Three hundred and forty-five items of literature were considered in the assembly of systems' information. From this initial database, 153 items were screened as yielding sufficient detail to provide information on different aspects of a range of farrowing systems, including design characteristics and performance data (Table 1). The remaining literature, although not able to be used in the database, could be used to aid discussion of other aspects of interest regarding loose farrowing accommodation. The majority of information came from scientific papers (72%), with technical reports (13%), theses/dissertations (2%), conference proceedings and presentations (13%) also contributing to the database. Initially, 30 different farrowing systems were identified, which were then grouped based on common features and reduced to 14 categories. These systems were then defined based on the average data collated from the database and their physical characteristics described (Tables 2a and b). As with other work summarising farrowing systems and assessing welfare (Johnson and Marchant-Forde, 2009), there are a number of caveats to address concerning the methodology: when summarising data, inevitably, details of particular studies are lost and such details may be contributing factors to certain production results in specific studies. For example breed differences, sow parity and previous experiences, and the similarity between dry sow accommodation and farrowing accommodation have all been shown to influence piglet survival (Damm *et al*., 2002; Thodberg *et al*., 2002; Canario *et al*., 2006). In addition, the data collected on each system are imbalanced, with some systems having only limited information from a small number of studies (e.g. Mushroom pens) and others being more abundant (e.g. conventional crates). However, summary data were required to sensibly define the systems in terms of their physical characteristics (Tables 2a and b), to determine how well they meet the design criteria to satisfy biological needs (Figure 1), to gather information on production performance (Table 3) and to estimate information on their investment costs. In addition, given that some data (particularly for the farrowing crates) were obtained from somewhat dated literature, expert opinion and current knowledge were sought to determine whether the definition of systems was sensible. To provide as much information as possible about the quality of the systems' data, standard errors and sample sizes for each piece of information summarised are presented in the tables and it should be noted that the sample sizes are variable depending on how many items of literature provided a specific piece of information.

Table 1 *References used to develop the database of summary information, define farrowing systems (Tables 2a and b) and determine production information (Table 3). References are numerically coded (see reference list) and then grouped based on the information collected from them*

Information provided by references	References
System characteristics only	1 to 38
Production only	39 to 66
Costs only	None
System characteristics + production only	67 to 140
System characteristics + costs only	141
Production + costs only	142, 143
System characteristics + production + costs	144 to 153

The 14 systems fall into five main categories of commercially available farrowing accommodation, which are briefly described below and further detailed in Tables 2a and b:

Conventional farrowing crates. The farrowing crate was first commercially introduced in the 1960s to provide more efficient management and control over sows and to reduce live-born piglet mortality (Robertson *et al*., 1966). Typically, tubular metal bars run horizontally along the length of the crate, with additional bars positioned above the sow to prevent escape via climbing or jumping. The crate is designed to restrain the sow to limit her posture changes and movements. A water and food trough is situated at the front with a (often adjustable) gate at the back. This crate is situated in a larger pen accessible to the piglets (Table 2a). Flooring is usually fully or part-slatted, with pens usually having a solid floor or mat for the piglet resting area.

Modified crates. These systems essentially involve a widening of the existing farrowing crate to either allow the sow to be able to turn around throughout farrowing and lactation (e.g. ellipsoid – Lou and Hurnik, 1994) or restrain the sow during farrowing before opening the crate up approximately 5 to 7 days post-farrowing (e.g. open crate – Weber, 2000). Such systems were designed to allow the sow greater freedom of movement within the existing footprint of a conventional crate space and to retain the ability to restrain the sow if necessary.

Pens. These systems include a range of modified designs in which the crate is absent: the hillside or sloped pens (e.g. hillside pens – Collins *et al*., 1987) attempt to occupy a footprint similar to that of the conventional farrowing crate with fully slatted floors that are profiled with the intention of directing piglets towards the creep area and away from the sow lying area; mushroom pens are designed to occupy a

Table 2a *Physical characteristics of farrowing and lactation systems where sows are kept individually with their piglets in indoor accommodation, as determined by literature review*

		Characteristic								
		Floor space (m^2; ±s.e.)		Substrate[†]	Flooring				Heat (°C)	
System	Systems included	Sow	Piglets	(kg; ± s.e.)	Type	Material	Enclosure (no. of solid walls)	Piglet Protection	Ambient (± s.e.)	Local
Crates										
Conventional	Crate (*n* = 158)	1.23 (0.04) (*n* = 104)	3.61 (0.13) (*n* = 98)	0.41 (0.23) (*n* = 116)	Slatted (32%) Solid (27%) Part-slatted (24%) Perforated round slats (17%) (*n* = 128)	Concrete (28%) Plastic (17%) Metal slats (20%) Plastic-coated metal (17%) Concrete solid, metal slats (11%) Other (8%)	0 (sows can see over low solid walls) (*n* = 126)	Rails (100%) (*n* = 127)	21.25 (0.44) (*n* = 53)	Heat lamp (69%) Heat mat (24%) Heat bars (4%) None (3%) (*n* = 75)
Modified	Turnaround/Ellipsoid (*n* = 8) Ottawa (*n* = 2)	Floor space = 2.28 (0.25) Planar space* = 2.82 (0.48) (*n* = 7)	4.27 (0.25) (*n* = 7)	0 (*n* = 6)	Slatted (22%) Solid (11%) Perforated round slats (67%) (*n* = 7)	Concrete (11%) Plastic (11%) Plastic coated metal (67%)	0 (sows can see over low solid walls) (*n* = 7)	Rails (100%) (*n* = 7)	19.92 (1.44) (*n* = 6)	Heat lamp (40%) Heat bars (60%) (*n* = 5)
	Hinged/Swing-side (*n* = 15)	Closed = 2.01 (0.41) Open = 4.71 (0.66) (*n* = 11)	5.22 (0.55) (*n* = 11)	0.28 (0.17) (*n* = 9)	Slatted (50%) Solid (25%) Part-slatted (13%) Perforated round slats (13%) (*n* = 9)	Concrete (33%) Plastic (33%) Plastic coated metal (17%) Concrete solid, metal slats (17%)	0 (sows can see over low solid walls) (*n* = 9)	Rails (100%) (*n* = 8)	22.75 (2.17) (*n* = 4)	Heat lamp (17%) Heat mat (33%) Other (17%) None (33%) (*n* = 6)
Pens										
Simple	Simple (*n* = 94)	11.72 (1.22) (*n* = 78)	10.42 (1.03) (*n* = 80)	2.80 (0.63) (*n* = 50)	Slatted (12%) Solid (74%) Part-slatted (6%) Perforated round slats (8%) (*n* = 78)	Concrete (59%) Plastic (5%) Metal slats (6%) Plastic coated metal (8%) Other (22%)	0 (20%) 1 (16%) 2 (12%) 3 (1%) 4 (48%) 4 + roof (3%) (*n* = 75)	None (69%) Rails (25%) Other (6%) (*n* = 108)	20.20 (0.67) (*n* = 26)	Heat lamp (91%) Heat mat (6%) None (3%) (*n* = 32)
Designed	Schmid (*n* = 16) FAT1 (*n* = 3) FAT2 (*n* = 5) Werribee farrowing pen (*n* = 10) Get away pens (*n* = 9) Other (*n* = 9)	7.56 (0.40) (*n* = 57)	7.26 (0.24) (*n* = 48)	2.49 (0.36) (*n* = 36)	Slatted (2%) Solid (32%) Part-slatted (64%) Perforated round slats (2%) (*n* = 51)	Concrete (25%) Plastic (2%) Concrete solid and metal slats (34%) Concrete solid and plastic slats (26%) Other (13%)	2 (8%) 3 (57%) 4 (26%) 4 + roof (9%) (*n* = 51)	None (28%) Rails (40%) Sloped walls (24%) Other (8%) (*n* = 41)	19.67 (0.71) (*n* = 22)	Lamp (45%) Mat (30%) Bars (2%) None (23%) (*n* = 41)
Sloped	Hillside pen (*n* = 5)	2.42 (0.09) (*n* = 4)	3.39 (0.04) (*n* = 4)	0 (*n* = 4)	Perforated round slats (100%) (*n* = 4)	Metal slats (25%) Plastic coated metal (75%)	0 (100%) (*n* = 3)	None (75%) Rails (25%) (*n* = 4)	Not reported	Lamp (100%) (*n* = 1)
Mushroom	Mushroom (*n* = 1)	3.74 (n/a) (*n* = 1)	6.34 (n/a) (*n* = 1)	0 (*n* = 1)	Perforated round slats (100%) (*n* = 1)	Plastic (100%)	0 (100%) (*n* = 1)	Mushroom posts (100%) (*n* = 1)	Not reported	Mat (100%) (*n* = 1)

Data provided as average absolute values (i.e. space, substrate and ambient temperature) ± s.e. or percentage of studies where systems provided a specific characteristic (i.e. type of flooring, piglet protection mechanism or supplementary heat and amount of enclosure). Sample sizes (*n*) show number of studies providing information for each characteristic.

*Planar space refers to the space available at the sow's shoulder height and in these specific studies this space was enough for the sows to turn around in.

[†]Straw or chopped straw was the most common form of substrate used.

Table 2b *Physical characteristics of indoor group and outdoor farrowing and lactation systems, as determined by literature review*

		Characteristic								
		Floor space (m²; ± s.e.)			Flooring				Heat (°C)	
System	Systems included	Sow	Piglets	Substrate† (kg; ± s.e.)	Type	Material	Enclosure (no. of solid walls)	Piglet protection	Ambient (± s.e.)	Local
Group systems										
Swedish-type systems	Ljungström (*n* = 4)	8.81 (0.96) (*n* = 4)	7.95 (1.38) (*n* = 4)	6.45 (4.76) (*n* = 3)	Solid (75%) Part-slatted (25%) (*n* = 4)	Concrete (100%)	3 (25%) 4 (75%) (*n* = 4)	None (25%) Rails (75%) (*n* = 4)	26.20 (n/a) (*n* = 1)	Lamp (66.67%) None (33.33%) (*n* = 3)
	Thorstensson (*n* = 13)	17.07 (5.62) (*n* = 10)	4.84* (0.38) (*n* = 9)	14.62 (9.15) (*n* = 7)	Slatted (9%) Solid (91%) (*n* = 11)	Concrete (91%) Plastic-coated metal (9%)	4 (70%) 4 + roof (30%) (*n* = 10)	None (50%) Rails (20%) Sloped walls (30%) (*n* = 10)	21.00 (n/a) (*n* = 1)	Lamp (43%) Mat (29%) None (29%) (*n* = 7)
	Free-access nests then group (*n* = 17)	18.70 (5.77) (*n* = 6)	8.33* (2.53) (*n* = 6)	10.64 (3.95) (*n* = 5)	Solid (87%) Part-slatted (13%) (*n* = 8)	Concrete (63%) Plastic (13%) Concrete solid and metal slats (13%) Other (13%)	1 (13%) 2 (25%) 4 (63%) (*n* = 8)	None (29%) Rails (43%) Sloped walls (29%) (*n* = 7)	17.75 (0.25) (*n* = 2)	Lamp (33%) Bars (67%) (*n* = 3)
	Crated for farrowing then group (*n* = 7)	Restrained = 1.94 (0.62) Grouped = 9.71 (1.87) (*n* = 7)	5.39* (0.73) (*n* = 5)	0.14 (0.14) (*n* = 6)	Slatted (29%) Solid (43%) Part-slatted (29%) (*n* = 7)	Concrete (60%) Plastic-coated metal (20%) Concrete solid with metal slats (20%)	0 (67%) 4 (33%) (*n* = 6)	None (17%) Rails (83%) (*n* = 6)	21.40 (n/a) (*n* = 1)	Lamp (100%) (*n* = 3)
	Family pen (*n* = 6)	41.17 (22.11) (*n* = 6)	6.09* (0.44) (*n* = 6)	14.98 (4.06) + branches (*n* = 5)	Solid (100%) (*n* = 6)	Concrete (100%)	2 (17%) 3 (17%) 4 (33%) 4 + roof (33%) (*n* = 6)	None (33%) Rails (67%) (*n* = 6)	16.50 (1.50) (*n* = 2)	Lamp (100%) (*n* = 3)
Outdoor systems										
Kennels	Kennel with run, Solari (*n* = 5)	7.00 (1.00) (*n* = 3)	5.50 (0.50) (*n* = 3)	1.58 (0.01) (*n* = 2)	Solid (100%) (*n* = 3)	Concrete (67%) Other (33%)	4 + roof (100%) (*n* = 3)	None (33%) Rails (67%) (*n* = 3)	14.00 (n/a) (*n* = 1)	Mat (100%) (*n* = 3)
Outdoor	Outdoor (*n* = 35)	376.93 (119.96) (*n* = 10)	3.54 (0.13) (*n* = 35)	14.65 (2.13) (*n* = 10)	Solid (100%) (*n* = 32)	Earth (97%) Other (3%)	4 + roof (100%) (*n* = 32)	None (10%) Sloped walls (90%) (*n* = 29)	20.22 (2.14) (*n* = 11)	None (100%)

Data provided as average absolute values (i.e. space, substrate and ambient temperature) ± s.e. or percentage of studies where systems provided a specific characteristic (i.e. type of flooring, piglet protection mechanism or supplementary heat and amount of enclosure). Sample sizes (*n*) show number of studies providing information for each characteristic.

*Nest space available to the piglets, although some piglets maybe able to access sow space before official integration.

†Straw or chopped straw was the most common form of substrate used.

crate footprint, on fully slatted floors, but provide protection for the piglets from sow posture changes by replacing rails with mushroom-shaped protrusions placed throughout the pen (BPEX, 2004). Fairly simple pen designs include larger, solid-floored, straw-based systems (reviewed in Phillips and Fraser, 1993). The most elaborate of these systems are the more designed pens with defined regions including separate dunging and lying areas and additional pen 'furniture' such as rails or sloped walls to assist sow posture changes and protect piglets (e.g. Schmid pen – Schmid, 1993; FATs (Swiss Federal Research Station for Agricultural Economics and Engineering, Tänikon, Switzerland) – Weber, 2000; Werribee Farrowing Pen – Cronin *et al.*, 2000).

Group systems. These systems allow sows and litters to mix before weaning (Table 2b). The majority are based on multi-suckling accommodation; both sows and piglets are afforded a much greater amount of space and systems are often deep-straw bedded. For farrowing, sows are initially individually housed in either pens or crates, but are integrated with their litter into groups in larger multi-suckling pens between 10 and 21 days post-farrowing (e.g. Ljungström – Bäckström *et al.*, 1994; Goetz and Troxler, 1995; Marchant *et al.*, 2000; McGlone, 2006). Alternatively, sows are already grouped before farrowing and have free access to individual nest boxes for farrowing, which may or may not be removed 7 to 10 days post-farrowing (Thorstensson – Mattsson, 1996; Marchant *et al.*, 2001; free access systems: e.g. get away pens – Bøe, 1993; freedom farrowing – Baxter, 1991; crated then grouped – Marchant *et al.*, 2000). The Family Pen system was derived from observing sows and piglets under semi-natural conditions and attempting to fulfil the observed needs in a more complex group design (Stolba and Wood-Gush, 1984; Kerr *et al.*, 1988).

Outdoor systems. These are systems with low capital investment and running costs, where sows and their piglets are housed individually, outdoors in farrowing arks or huts, with access to individual or group paddocks. Different ark and hut designs are available and have been described in detail elsewhere (e.g. Honeyman *et al.*, 1998; Baxter *et al.*, 2009). Outdoor runs with kennels or Solari pens (e.g. Grissom *et al.*, 1990; BPEX, 2004) are systems that attempt to offer more managerial control than full outdoor systems by providing a separate heated creep area inaccessible to the sow, in addition to operating on a smaller footprint, with kennels often aligned next to each other.

Production information

As with data summarising physical characteristics, information regarding the production results of different systems was varied in the quantity and details for each system (Table 3). The most complete sets of production data available were the total litter size, number born alive, percentage total mortality (stillborn + live-born) and percentage live-born mortality. Further information of interest regarding both production and sow welfare (e.g. weaning to oestrus interval) was only available from a limited number of studies and too sparse to populate the database, but individual items could be used to aid discussion about such production parameters. As with other data in this review, there are certain caveats to be discussed – most importantly, the issue of litter size. With increasing litter size, the probability of survival decreases (e.g. Roehe and Kalm, 2000) and therefore imbalances in this could influence the production figures reported for each system. For this evaluation, there is no attempt to correct mortality data to a standardised litter size for each piece of literature used, as this would require access to a more detailed level of individual data that many studies failed to provide. However, there is an attempt to correct the summarised mortality data for each system by standardising litter size and using a correction factor. Therefore, Table 3 not only reports the simple descriptive statistics for each system but also presents corrected data to provide an indication of the influence of litter size and the issues of litter size are discussed further in later sections.

Development of the welfare design index (WDI)

From a review of the biological needs of the sows and piglets during the three main phases of farrowing: nest-building, parturition and lactation (Baxter *et al.*, 2011a), design criteria for accommodation were proposed that were considered to best meet those needs. These criteria were further enhanced by accounting for the needs, particularly of piglets, of animals housed under indoor and more intensive conditions. For example, in the wild, piglets do not have or require a separate 'creep' area, inaccessible to the sow; however, protection is afforded somewhat by the properties of the nest-site (Baxter *et al.*, 2009). Under indoor conditions, unless animals are housed on deep straw bedding, no flooring offers such properties. Therefore, provision of piglet protection must be added as a design criterion. Within the farrowing area, protective properties of floors, walls (e.g. sloped or rails added) and the provision of a separate heated area, inaccessible to the sow, were considered. In addition, the needs of the stockperson for the safe handling of livestock have been addressed, because this interacts with the needs of the piglets in terms of health and well-being. To document how well the 14 systems met these design criteria, a WDI was developed. To assign a single value (score) to each system, a set of over 50 questions (Tables 4a and b) was 'asked' based on the identified biological needs of both sows and piglets during the different phases described. The questions concerned different attributes of the system including both direct (e.g. quantity of space and substrate, ambient temperature, etc.) and indirect components (e.g. facilitation of hygiene and health care). The issue of piglet mortality (considered a welfare criterion because piglets may suffer rather than being killed instantaneously) was tackled in two ways: firstly, within the WDI, questions relating to design features that may prevent piglet death were asked. For example, crushing is the most common ultimate event preceding live-born death, although hypothermia and starvation are often underlying factors resulting in the neonate being more susceptible (Edwards, 2002), and thus questions relating to piglet microclimate and protection during sow posture changes are prominent. Secondly, production information

Table 3 *Average production results (±s.e.) and study sample size (n) for defined farrowing systems. Mortality data have also been corrected for a standardised litter size of 11 piglets*

System	Litter size (±s.e.)	Born alive (±s.e.)	Total mortality (%; ±s.e.)	Live-born mortality (%; ±s.e.)	Average number of litters studied (±s.e.)	Total mortality (%) as corrected for by litter size of 11	Live-born mortality (%) as corrected for by litter size of 11
Crate							
Conventional crate	11.1 (0.14) *n* = 80	10.4 (0.16) *n* = 67	18.3 (0.63) *n* = 96	11.5 (0.59) *n* = 78	902.0 (503.68) *n* = 151	18.1	11.3
Modified crates							
Turnaround/ Ellipsoid	10.0 (0.49) *n* = 3	8.9 (0.05) *n* = 2	16.3 (2.68) *n* = 4	11.4 (2.50) *n* = 5	28.4 (18.07) *n* = 8	18.3	13.4
Hinged/Swing-side	11.9 (0.13) *n* = 13	10.9 (0.15) *n* = 9	17.4 (0.95) *n* = 14	11.7 (1.26) *n* = 10	2327.4 (1138.53) *n* = 18	15.6	9.9
Pen							
Simple	11.7 (0.28) *n* = 40	11.3 (0.28) *n* = 38	20.7 (1.21) *n* = 35	14.2 (0.94) *n* = 38	297.3 (154.02) *n* = 90	19.3	12.8
Designed	11.8 (0.28) *n* = 35	10.8 (0.26) *n* = 24	16.6 (0.88) *n* = 35	11.8 (0.80) *n* = 29	635.4 (390.83) *n* = 57	15.0	10.2
Sloped/Hill-side	10.7 (0.28) *n* = 4	10.1 (0.38) *n* = 4	19.6 (0.59) *n* = 4	12.2 (1.42) *n* = 4	17.3 (4.09) *n* = 4	20.2	12.8
Mushroom	12.0 (n/a) *n* = 1	11.3 (n/a) *n* = 1	16.4 (n/a) *n* = 1		105.0 (n/a) *n* = 1	15.4	
Group							
Ljungström	12.5 (n/a) *n* = 1	11.9 (0.35) *n* = 2	28.0 (n/a) *n* = 1	22.3 (2.30) *n* = 2	18.0 (3.61) *n* = 3	25.0	19.3
Thorstensson	12.1 (0.24) *n* = 9	11.3 (0.18) *n* = 9	23.7 (2.26) *n* = 13	19.2 (2.05) *n* = 8	94.1 (54.42) *n* = 14	21.5	17.0
Free access nests then group	10.5 (0.90) *n* = 4	10.9 (0.24) *n* = 5	18.7 (6.01) *n* = 3	17.0 (1.68) *n* = 15	40.8 (8.57) *n* = 14	19.7	18.0
Crated for farrowing	11.1 (0.67) *n* = 5	11.0 (0.14) *n* = 3	16.6 (4.46) *n* = 6	18.1 (5.14) *n* = 5	650.0 (610.81) *n* = 8	16.8	18.3
Family pen	13.0 (n/a) *n* = 1	10.8 (0.21) *n* = 5	22.3 (2.88) *n* = 5	18.8 (4.13) *n* = 3	243.6 (168.95) *n* = 6	18.3	14.8
Outdoor							
Kennel, Solari	11.7 (0.84) *n* = 3	10.8 (0.57) *n* = 3	20.4 (0.29) *n* = 3	15.0 (2.33) *n* = 3	122.3 (44.80) *n* = 4	19.0	13.6
Outdoor	11.9 (0.44) *n* = 10	9.2 (0.42) *n* = 20	17.0 (2.05) *n* = 26	16.8 (3.99) *n* = 10	354.6 (237.06) *n* = 27	15.2	15.0

documenting piglet mortality in each system was collated and summarised (Table 3).

The review that formed the basis for the WDI documented the considerable amount of literature describing the biological needs of the sow and her piglets during the different phases of farrowing and lactation and identified and summarised suitable design criteria to accommodate biological needs (Baxter *et al.*, 2011a). However, this review also served to highlight that, despite the abundance of work in this area, there remain outstanding gaps in knowledge requiring additional and detailed research, for example the quantification of space and substrate needed at specific stages. Where data on these specifics were lacking, certain assumptions were made for the WDI, based on biological argument. An example of just such a dilemma occurred when asking questions about space; the welfare of the sow is increased when moving from a restricted space (i.e. a farrowing crate), where she is unable to turn around, to a more open space, where she can turn around. Scientific evidence looking at the stress physiology of sows housed in crates or loose shows elevated cortisol under restricted conditions (Lawrence *et al.*, 1994; Jarvis *et al.*, 1997; Jarvis *et al.*, 2002), supporting this statement. Furthermore, it can be stated that sow welfare is increased when she is given space, permitting increased ambulation (Jensen, 1986), particularly during the nest-building phase. From the first review (Baxter *et al.*, 2011a), it was determined that approximately 5 m^2 would facilitate this increase in ambulation. Although no objective data exist to our knowledge that support the statement that the welfare of the sow is increased if, for example, she has 10 m^2 space to use, observations of sows under natural or semi-natural conditions report that they cover large distances at this time (Jensen, 1986). We therefore conclude that, for the nest-building phase, a larger space would allow better expression of motivated behaviour and therefore extra points are awarded if the system facilitates this. This process is an example of the biological argument made to develop the WDI where quantifiable data were missing and, as with other work to quantify welfare (Bracke *et al.*, 1999a and 1999b), it attempts to perform the best possible assessment based on the knowledge that is available.

To develop an overall score for each system, questions were phrased in such a way that a positive response was always considered positive for welfare and then the ratio of positive to negative responses was calculated. It was not intended that a positive response, and therefore a positive attribute of the system, would automatically cancel out any negative one or vice versa. Attributes are likely to lead to positive or negative outcomes with different intensities and therefore should not be considered equal. This point raises the issue of weighting attributes within the WDI.

Weighting the WDI

The WDI was weighted to account for the fact that the welfare of each individual animal should be considered of equal importance. Thus, questions relating directly to piglet welfare were multiplied by an average litter size of 11 (i.e. the reported industry average live-born litter size in the United Kingdom; BPEX, 2009). Tables 4a and b provide examples of how four different systems were scored and demonstrate which questions relate to sows (Table 4a) and which to piglets (Table 4b) and therefore which are weighted to account for each piglet in the litter. Weighting was only applied to attributes directly related to piglet welfare, and the issue of how to weight indirect needs (e.g. attributes that satisfy the sow and promote positive maternal behaviour that indirectly benefits piglets) is discussed later.

The second aspect of weighting relates to the number of questions asked about a given attribute of a system, and therefore, the extent to which its presence or absence influences the final score awarded. Scoring utilised multiple questions about an attribute to emphasise its importance to the animal at any particular phase, recognising the temporal nature of biological needs. For example provision of substrate is known to be of particular importance to the sow during nest-building and it can be considered an attribute with multiple benefits, given its properties to satisfy nest-building motivation (Damm *et al.*, 2003; Pedersen *et al.*, 2003) and provide thermal and physical protection for the piglets once born (Mount, 1967; Baxter *et al.*, 2009), and physical comfort for the sow (Baxter, 1983). Thus, this attribute is more heavily weighted during nest-building, by asking additional questions about substrate relating to needs during this phase that are not asked during the lactation phase, where there is no evidence to suggest that substrate is of equal importance. Tables 4a and b list the WDI questions, whose rationale is discussed in detail in Baxter *et al.* (2011a). Such a process is obviously a simplification, because it is based more on the number than the intensity of needs, but, while open to debate regarding weighting of individual attributes, has been made as transparent as possible.

Describing the financial performance of the systems

There is a dearth of data relating to the financial performance of systems (Table 1). As a result, to assign some standardised estimation of investment costs to each of the 14 systems, expert consultancy was utilised. Descriptions of each system (based on the scientific literature – Tables 2a and b) were given to a commercial farm buildings specialist (Mr Glyn Baker, Quality Equipment Ltd, personal communication) for economic evaluation. Investment costs per sow place for different farrowing and lactation housing systems included the costs of materials, design and labour for the manufacture of the basic internal structures (Table 5). The costs of accessories and furniture such as flooring materials, creep areas, bars, gates, walls, drinkers, feeders, etc. were also included in the total investment costs for every system. However, it was assumed that the shell of the building was in place, which includes plumbing, electricity and ventilation, and that differences in farrowing accommodation required no changes in any other parts of the farm. In addition to investment costs, economic evaluation of a system should include the cost of running the system in terms of labour input and, ideally, utility usage. A very limited number of studies provided information on labour input (Table 1) and data that were available were only for certain systems (Table 5). No information could be found on

Table 4a *Questions 'asked' of each system, based on the biological needs of the sow during the different phases of farrowing (nest-building, farrowing and lactation) as proposed by Baxter et al. (2011a). Answers for four different systems provided*

		Crate		Designed pen		Thorstensson		Outdoor*	
Phase	Question of system	Yes	No	Yes	No	Yes	No	Yes	No
Nesting-building	Can the sow isolate herself?		1	1		1		1	
	Is there possibility for visual contact with other sows?	1		1		1		1	
	Is there 1 wall?		1	1		1		1	
	Are there 2 walls?		1	1		1		1	
	Are there 3 walls?		1	1		1		1	
	Are there 4 walls?		1		1	1		1	
	Is there a roof on the area designed for farrowing?		1		1	1		1	
	Is there enough space for the sow to turnaround (floor space = 2.44 m^2 and planar space (3.17 m^2)?		1	1		1		1	
	Is there space for increased activity for seeking and building behaviours? (at least 4.9 m^2)		1	1		1		1	
	Is the space defined into separate areas for different activities (e.g. feeding and dunging)?		1	1		1		1	
	Is the space above 5 m^2 to allow at least two defined areas?		1	1		1		1	
	Is the space above 10 m^2 to allow at least three defined areas?		1		1	1		1	
	Is any substrate given?	1		1		1		1	
	Is substrate above 2 kg? (the minimum recommended for nesting)		1	1		1		1	
	Is substrate enough to cover the floor of the nest area provided? (0.60 kg covers 1 m^2 at a 5 cm depth)		1	1		1		1	
	Is substrate deep bedded? (1.20 kg covers 1 m^2 at a 10 cm depth)		1		1	1		1	
	Is substrate complex (i.e. opportunity to gather long-stemmed straw and other materials)?		1		1	1		1	
	Is flooring suitable for nesting material?		1	1		1		1	
	Is flooring pliable for rooting?		1		1	1		1	
	Is ambient temperature suitable for the sow – not above 20°C for heat stress?		1	1			1	1	
Farrowing	Is the space defined with a separate nest area?		1	1		1		1	
	Is the sow loose for farrowing?		1	1		1		1	
	Is there enough space to turnaround for piglet inspection and grouping of piglets?		1	1		1		1	
	Is the nest-site undisturbed (as determined by degree of enclosure)?		1	1		1		1	
	Is substrate enough to cover the floor of the nest area provided? (0.60 kg covers 1 m^2 at a 5 cm depth)		1	1		1		1	
	Are there sloped or vertical walls to aid sow posture changes?		1	1			1	1	
	Is the space defined with separate lying and dunging areas?		1	1		1		1	
Lactation	Is the sow loose?		1	1		1		1	
	Does the flooring prevent sow slip injury?		1		1	1		1	
	Does the floor prevent sow teat injury (solid)?		1	1		1		1	
	Is there a get away area for the sow?		1		1	1		1	
	Can the sow physically contact other sows?		1	1		1		1	
	Is there visual contact with other sows?	1		1		1		1	
	Is there the opportunity for full integration with sows?		1		1	1			1
	Are there sloped or vertical walls to aid sow posture changes?		1	1		1		1	
	Is the ambient temperature below 22°C?	1		1			1	1	

*Outdoor system described as individual farrowing and lactation.

Table 4b *Questions 'asked' of each system, based on the biological needs of the piglets during farrowing and lactation, as proposed by Baxter et al. (2011a). Answers are multiplied by 11 to reflect an average litter size of 11 piglets as determined by national recording data (BPEX, 2010). Answers for four different systems provided as examples*

		Crate		Designed pen		Thorstensson		Outdoor*	
Phase	Question of system	Yes	No	Yes	No	Yes	No	Yes	No
Farrowing	Is the floor profiled (i.e. to assist with piglets finding the creep)?		11		11		11		11
	Is there protection for the piglets from sow posture changes (e.g. sloped walls, farrowing rails, 'furniture')?	11		11		11		11	
	Is the temperature above uncontrolled/ambient temperature?	11		11		11			11
	Is the temperature above 22°C to minimise piglet hypothermia?		11		11	11			11
	Is there a local heat source for the piglets?	11		11		11			11
	Is there protective substrate (e.g. deep bedding)?		11		11	11		11	
	Is the flooring suitable to reduce conductive heat loss (i.e. solid insulated or deep bedding)?		11	11		11		11	
	Is there opportunity for safe handling by the staff (i.e. sow lock-in area)?	11			11		11		11
Lactation	Does the flooring prevent piglet foot injury (e.g. solid to prevent coronary band injury)?		11	11		11		11	
	Does the floor protect piglet legs? (e.g. deep bedding, suitable plastic coating)		11		11	11		11	
	Is the flooring hygienic (sloped or slatted/part-slatted)?	11			11		11		11
	Is there continuous sow contact for piglets?	11		11			11		11
	Is there an opportunity for piglets to integrate with other litters?		11		11	11		11	
	Does the system limit disease transfer between non-litter mates?	11		11			11		11
	Is there a separate area for piglet protection, inaccessible to the sow (e.g. a creep)?	11		11			11		11
	Is there protection for the piglets from sow posture changes (e.g. sloped walls, farrowing rails, 'furniture')?	11		11		11		11	
	Is there a local heat source above 22°C?	11		11		11			11
	Is there enrichment for piglets via adequate social space (e.g. above 5 m^2)?		11	11		11		11	
	Is there enrichment for piglets via provision of substrate?		11	11		11		11	
	Is there opportunity for safe handling by the staff?	11			11		11		11

*Outdoor system described as individual farrowing and lactation.

Table 5 *Cost per sow place and reported labour costs ((±s.e.) and study number (n)) for defined system*

System	Cost per sow place (£)[a]	Labour (hrs per sow per year)		
		Hours per sow per year (±s.e.)	Reference number where data obtained	Average number of litters studied
Crate				
Conventional crate	1843	6.96 (1.11)	142 to 146, 150 to 152	127
Modified crates				
Turnaround/Ellipsoid	2912			
Hinged/Swing-side	1976	6.27 (2.41)	141, 151 to 152	134
Pen				
Simple	1989	12.76 (8.07)	143 to 144	41
Designed	2165	7.17 (1.17)	141, 144 to 146, 150 to 152	46
Sloped/Hill-side	1298			
Mushroom	2047			
Group				
Ljungström	2094	36.00 (n/a)	147	23
Thorstensson	3543	18.10 (n/a)[¶]	143	
Free access then group	2349	15.10 (n/a)	142	*
Crated for farrowing	2367			
Family pen	4593	44.94 (0.68)[¥]	148, 153	86
Outdoor				
Kennel, Solari	1856			
Outdoor	1014			

[a]Costs calculated based on supplying average data for defined systems to a consultant for estimates. Assumes building 'shell' is in place with drainage, ventilation and plumbing, but not flooring.
[¶]Data given as farms no information on number of litters.
*Data from model so no actual figures given on litter number.
[¥]Piglets weaned at 85 days in this particular system.
n/a = s.e. not applicable as only one data set.

other running costs. The data for labour inputs are presented as hours per sow per year and information from available resources was modified to achieve consistent units.

Results

Evaluating the welfare of systems

When the WDI is weighted for the number of piglets, the conventional farrowing crate scores 0.95 and the outdoor system scores 1.10. Modified crates only marginally increase their scores above 1.00 (Turnaround = 1.19; Swing-side = 1.37). The designed pen scores highest in the pen category (1.64), with the simple pen only scoring marginally higher than the conventional crate (1.03) as a consequence of its negative characteristics regarding piglet protection. Among the group systems, the Thorstensson system scores the highest (2.20), with the crate for farrowing, followed by a group lactation system actually scoring lower than the conventional crate (0.90). This occurs because the sow is restrained during nesting and farrowing, as in the conventional crate, but unlike the conventional crate, the protective elements and managerial advantages are removed during lactation for the piglets and stockpersons. To show the influence of weighting, Figure 1 compares weighted and non-weighted scores (i.e. the sow is given equal importance to the litter as a whole rather than each individual piglet). This demonstrates that without weighting, all systems score much higher than the conventional farrowing crate.

Production performance of systems

Table 3 summarises the production data available for all systems. Total mortality (stillbirths + live-born mortality) was the most complete set of data relating to production efficiency and ranged from 16.3% in the Turnaround crates to 28.0% in the Ljungström system. The modified crates offered better overall survival rates than the conventional crate (Table 3), with the difference appearing to be in the percentage of stillbirths, as live-born mortality was very similar in crates (11.5%), Turnaround crates (11.4%) and Swing-side crates (11.7%). The Mushroom pen had the lowest mortality of the pen systems (16.4%); however, these data stem from one single study. From the more populated data sets in this pen category, the designed pens averaged the lowest total mortality (16.6%). Despite favourable WDI scores, the group systems had relatively high mortality levels, except for the system that restrained the sow in a crate for nest-building and farrowing phases (16.6%). The outdoor system offered a competitive level of survival (total mortality = 17.0%) compared with the conventional crated system (18.3%). In all these comparisons, however, it must be borne in mind that initial litter size was not always comparable and is a potential confounding factor that is discussed later.

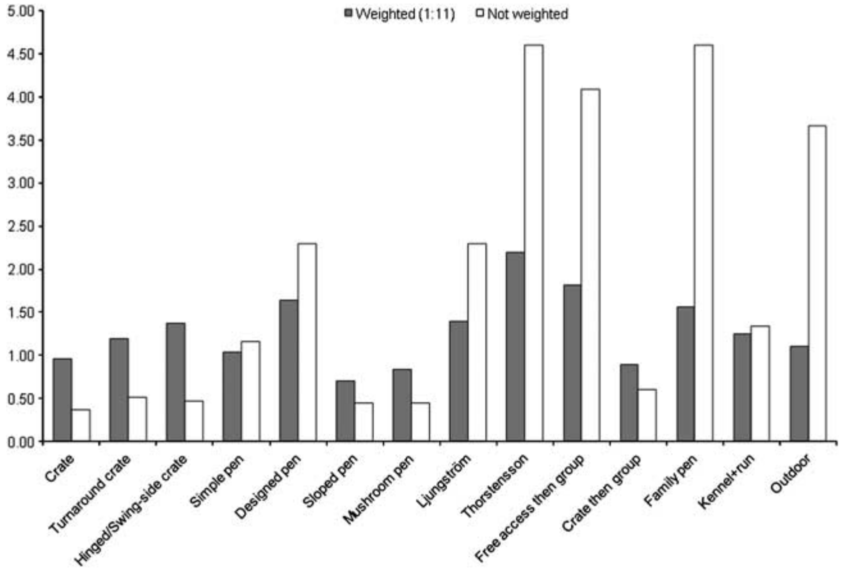

Figure 1 Welfare design scores for each defined system, as determined by assessing how well each system meets the biological needs of the animals during the three phases of farrowing: nest building, parturition and lactation. The differences between weighted scores (piglet criteria multiplied by 11 per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

Financial aspects of systems

Table 5 summarises the calculated investment costs of the defined systems and provides limited information on labour costs for selected systems. The additional floor space and 'furniture' required for the designed pens is reflected in the higher investment cost per sow place compared with simple pens (8.8% higher), crates (17.5% higher) and some modified crates (9.6% higher). Despite the relatively basic requirements of the Swedish-style group housing accommodation (e.g. large barn and simple wooden nest-boxes), the additional space afforded to each sow and its litter inflates the investment costs, via the costs of additional concrete flooring and penning/gating for the larger area, with the Thorstensson system twice as expensive as a conventional crated system. The Family Pen is the most expensive system, with the structural complexity of the design making it 2.5 times more expensive than a conventional farrowing crate. The Family Pen also has the highest labour requirements, with all group systems (with available data) averaging almost an extra 21.58 h per sow per year compared with conventional crates. Available data on modified crates suggest that there is relatively little difference regarding labour inputs compared with the conventional crates (6.27 *v.* 6.96 h respectively). Simple pens take twice as long to operate (12.76 h); however, designed pens are only marginally more time consuming (7.17 h) than conventional crates (6.96 h).

Discussion

A successful housing system should attempt to reconcile the 'triangle of needs' between sow, farmer and piglets, to maximise both productivity and welfare. From the data presented in this paper, no one system completely satisfies the needs of these three stakeholders and each system has different merits and drawbacks regarding their overall performance. The outdoor system, where it can be operated under suitable climate and soil conditions, has low capital and running costs, total pre-weaning piglet mortality at the lower end of reported national averages (15% to 20% – Leenhouwers *et al*., 2002; BPEX, 2009; Fowler, 2009) and has higher welfare design scores (whether weighted or not) than the conventional crate. However, challenges exist for animals kept outdoors, and efficiency will be at risk to climatic extremes (Algers and Jensen, 1990; Edwards and Zanella, 1996). For these reasons, indoor alternatives need to be considered and the merits and limitations of indoor systems with respect to welfare, production and economic performance will be discussed here. Alternative indoor accommodation needs to combine the managerial advantages of the conventional crates with the higher welfare standards afforded by the outdoor environments via the ability to fulfil certain biological needs. Such bridging systems need to emulate or surpass production levels in conventional systems and perform consistently across a range of farm conditions for widespread commercial implementation to be considered. From the data presented here, the designed pens appear to be the best option for an indoor alternative, with piglet mortality lower than conventional crates in the data sets reported, acceptable capital costs and scores from the WDI indicating that the system can better meet the biological needs of animals than other individually housed indoor systems. The descriptive data on these systems presented here and their subsequent assessment using the WDI illustrate where animals' needs are met.

Satisfying biological needs – the welfare attributes of farrowing systems

Designing a suitable housing system based on the biological specifications of the animals concerned involves asking questions about their needs, both physiological and behavioural.

The former include very obvious requirements including the provision of appropriate nutrition and climate to ensure maximum growth, development, health and productivity. The latter concept of 'behavioural needs' has been the subject of much debate and detailed scientific analysis (e.g. Dawkins, 1977; Baxter, 1983; Hughes and Duncan, 1988; Jensen and Toates, 1993). To develop questions for the WDI in the present review, the previous review (Baxter *et al.*, 2011a) first defined the term behavioural need and used the reasoning put forward by Baxter (1983) and Jensen and Toates (1993): 'behavioural need' describes the need to perform a specific behaviour pattern whatever the environment and even if the physiological needs that the behaviour serves are fulfilled in other ways. Possible behavioural needs can be catalogued by identifying species behaviours with important survival value that occur spontaneously in all environments and by measuring the preferences of animals (Hughes and Black, 1973; Dawkins, 1977). However, to demonstrate a true need, it should be shown that failure to meet this need results in a compromise in welfare by demonstrating negative consequences when motivated behaviours cannot be performed satisfactorily (e.g. performance of abnormal behaviour, physiological stress response or increased incidence of pathology; Baxter *et al.*, 2011a).

Apart from the two-stage system, involving initially crating the sow and then grouping during lactation, the group systems tend to score the highest on the WDI. This is true whether or not the scores are weighted for piglet number and reflects managerial and physical characteristics that allow the animals freedom to fulfil biological needs. When the WDI is weighted, the conventional farrowing crate scores higher than some of the individual pen designs, with most of the benefits being related to the piglet. When not weighted, as expected, the crate scores the worst because of the negative effects on sow welfare, predominantly as a result of close confinement. Although the modified crates attempt to improve the situation for sows by allowing greater freedom during lactation, this only equates to a marginal increase in the WDI score. The major issue with any confinement system is that it precludes certain behaviours that the animal has a strong motivation to perform and, in the case of all crated systems reviewed, the sows are confined during their most active phase of nest-building. This behavioural pattern is partially reliant on feedback from the farrowing environment and thus is strongly influenced by stimuli within that environment (Jensen, 1986; Wischner *et al.*, 2009; Baxter *et al.*, 2011a). However, even when the sow is not restrained at all, the system can still score poorly when attempting to meet biological needs. This is the case with some of the individual pen systems (i.e. sloped pens and Mushroom pens); such systems aimed to develop an alternative within the footprint of a farrowing crate place and to add certain design criteria that might reduce the risk to piglets from crushing (i.e. 'mushroom' protrusions to support sow posture changes – BPEX, 2004; sloped floors to encourage piglets into the creep – Collins *et al.*, 1987). However, these systems were built on fully slatted floors, with no reported provision of substrate – thus lacking a design criterion that confers many positive welfare points to both sows and piglets. Ultimately, these pens and the modified crates fail from a welfare perspective because they have been too economical with certain design criteria that are considered critical to fulfil biological needs.

As with any work attempting to assess the overall welfare attributes of a system, development of the WDI involved making certain decisions that ultimately influence the judgement of that system and therefore should be discussed. It is important to discuss why this method was developed rather than utilising some of the existing techniques, such as Risk Assessment Analysis (EFSA, 2007), semantic modelling (e.g. Bracke *et al.*, 2002a and 2002b), the Animal Needs Index (e.g. Bartussek, 1999) or Fraser's Behavioural Deprivation Index (Fraser, 1983). The method used in the current study assigns many of its points to identifiable attributes of the farrowing and lactation systems described, similar to the Animal Needs Index or Tiergerechtheitsindex (Bartussek, 1999). However, these models have been criticised for not having a transparent scientific basis (Bracke *et al.*, 2002a). Our index, however, has utilised scientific evidence to define the needs, describe the systems and assess their performance. There could be concern with the method of tallying the number of positive and negative responses and calculating a ratio to derive one score per system, because it might imply that a serious welfare disadvantage can be compensated for by a series of minor welfare advantages (cf. Spoolder *et al.*, 2003). Thus, an important element of welfare assessment is how best to weight certain attributes, or in the case of risk analysis, assess the intensity of the potential hazard, and this is a complex topic. In our evaluation, the list of questions in the WDI is derived by first identifying the minimum design criteria to satisfy biological needs and, as with the methods adopted by Keeling and Svedberg (1999) when assessing battery cages for hens, extra questions regarding an attribute then weight that attribute to allow a system to score more highly if certain criteria are provided. Thus, the scoring utilised additional questions about an attribute to emphasise or weight its importance to the animal in the system and to address the temporal nature of biological needs. For example, substrate is a known need and is an attribute that can satisfy the requirements for more than one dimension of the animals' needs. For example, substrate is particularly important for sows during the pre-farrowing phase to satisfy nest-building motivation (Damm *et al.*, 2003; Pedersen *et al.*, 2003), but it also has properties that provide thermal and physical protection for the piglets (Mount, 1967; Baxter *et al.*, 2009), physical comfort for the sow (Baxter, 1983) and behavioural enrichment for developmental functions of piglets (de Jong *et al.*, 2000). Therefore, questions about substrate were asked throughout the different phases of farrowing for both sow and piglets, giving it a high overall weighting in the WDI. Unwarranted double counting could also be a concern (Botreau *et al.*, 2007); however, this is overcome by distinguishing that the outcome of each measure is different from one dimension to another, by fulfilling different needs.

The potential trade-offs between sow welfare and piglet welfare represent another important issue and is at the very centre of the debate regarding the farrowing environment. For the WDI, it was important to decide whether the sow's welfare was of equal importance to her litter as a whole or equivalent to each individual offspring's welfare. Such a question involves both biological and ethical debate, which is beyond the scope of this review, but these weighting issues are discussed by other authors regarding welfare assessment (Bracke *et al*., 1999a). For the purposes of this paper, it was decided to give the benefit of the doubt and argue that each piglet is equal to the sow; thus, 'all to count for one, and nobody for more than one' (Bentham, 1789; Bracke *et al*., 1999a). Further prudence was demonstrated because weighting was only applied to attributes directly related to the piglet. Therefore, although maternal behaviour is paramount to piglet survival and maternal behaviour is known to be improved when the sow is provided with the correct stimuli to satisfy behavioural needs (Andersen *et al*., 2005; Pedersen *et al*., 2006), attributes relating directly to sow behavioural needs and indirectly to piglet needs were not weighted. The question of how to weight indirect needs is a relevant one, but again thorough discussion is not within the scope of this paper and the most parsimonious scoring system was adopted for this exercise to limit bias. However, one possibility would be to use expert opinion to determine the importance of these indirect needs. The use of expert opinion when scientific data are not available or inconclusive is another important issue regarding welfare assessment and one that raises concerns, as discussed by other authors (Bracke *et al*., 1999b). For the current study, as far as possible, scientific evidence informed the process of identifying design criteria (Baxter *et al*., 2011a) and ideally unequivocal science would be utilised throughout the welfare assessment of housing systems. However, it is clear from reviewing the scientific literature to determine biological needs and propose design criteria (Baxter *et al*., 2011a) that there are many gaps in the research, and there remains a surprising lack of quantifiable data and frustration with the lack of detail presented in the material that has been published. This makes an evaluation of certain husbandry systems based solely on scientific evidence difficult. Thus, where these data are absent, pragmatic approaches using stakeholder knowledge (in the case of this review: scientists regarded as experts in integrated pig science; pig industry representatives; and construction engineers) with consideration of practicalities (Barnett, 2007) were adopted here to attempt a thorough evaluation of systems.

Design detail

Attention to detail may be the key condition under which alternative housing systems will operate effectively. The design detail and then the management of a housing system may be more important for animal welfare than the system itself (Barnett, 2007). In addition, the design criteria, on which the welfare design score in this review were based, are considered as separate entities in the scoring system and recommendations are based on the properties of each criterion. However, inevitably, an animal will not consider each criterion separately and different criteria will interact. For example, based on reasoned opinion and scientific evidence, a peri-parturient sow requires a certain amount of space in which to perform 'seeking' behaviours for a nest site, but the complexity of space is likely to be just as important, if not more so. If the space is complex and dynamic, thus allowing greater opportunities for the animal to engage in different behaviours, it is likely to reduce the amount of space necessary to accommodate behavioural needs and hence the adverse consequences of confinement. The interaction between attributes of a system and how this influences overall welfare assessment is therefore another area that requires further investigation.

Production performance

The multifactorial nature of piglet mortality means that the sow, her piglets and their environment represent a complex dynamic, all contributing to piglet survivability (Baxter *et al*., 2008). From the results presented here, the designed pens have one of the lowest total mortality percentages and it is most likely that designing the accommodation to recognise this dynamic is partly responsible for favourable production results. For example, maternal behaviour is a key survival factor, possibly the most important survival factor in loose-housed farrowing systems (Arey, 1997), and designed pens provide an environment that incorporates stimuli that might improve the sow's interaction with her piglets (i.e. separate nesting sites, with solid flooring to accommodate nesting material). However, the group systems also provide these stimuli and such provision equates to high welfare design scores, but does not translate into acceptable production results, with piglet mortality still much higher than that reported in conventional crates. Potentially, there are other aspects of this system that might explain poor individual results and, when summarising data, there are issues regarding loss of information. By looking at the details of a study, it might be possible to pinpoint where a system has failed. For example factors known to influence mortality are breed (Canario *et al*., 2006), previous farrowing experience (i.e. parity; Jarvis *et al*., 2001) and gestational environment (Marchant and Broom, 1993). In addition, a major factor known to contribute to production outcomes, such as survivability, is initial litter size; with increasing litter size, the probability of survival decreases (e.g. Roehe and Kalm, 2000) and therefore imbalances in this parameter could influence the production figures reported for each system. To robustly assess the impact of a system on mortality, quality control data are needed, with systems being tested against each other under the same management conditions and with litter size being standardised. By extrapolating mortality to a standardised litter size for all systems, more information on performance could be attained, but again, this relies on good 'real' data initially to model the relationship between litter size and mortality in each system and such data are unavailable. At the very least, when trying to interpret the summarised data presented here, it is important to determine whether the relationship between mortality and litter size is the same across systems. Although to our knowledge such data have not been published, unpublished data from the

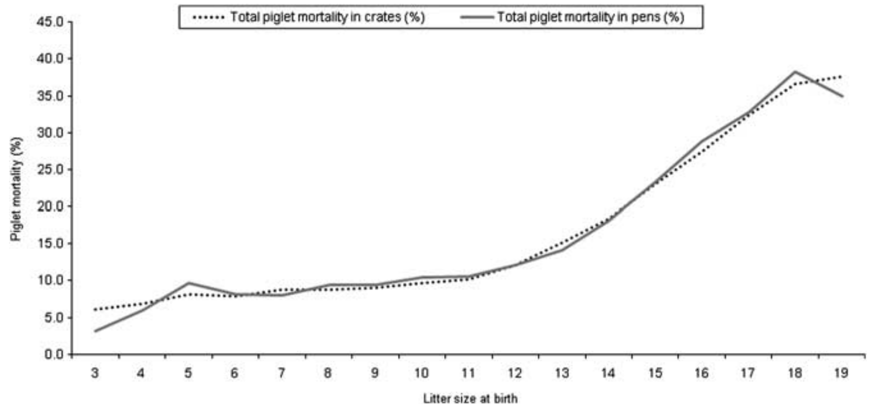

Figure 2 Effect of litter size on total mortality in conventional crated farrowing systems and loose-housed farrowing systems. Graph from unpublished data taken from a large-scale study by Weber *et al.* (2007).

comparative study by Weber *et al.* (2007) have been made available (Figure 2 – Roland Weber, personal communication). Figure 2 demonstrates that the relationship between mortality and litter size is the same in both conventional crates and loose-housed farrowing pens, and by using this as a reference point, we might assume that this relationship exists in other alternative systems. Although the relationship is not linear, it suggests that over the most typical range of commercial litter sizes, total mortality increases by approximately 1.5 to 2 percentage points for each additional piglet born. It is, however, likely that this relationship will be considerably affected by the quality of management.

Where data on all variables that might influence mortality are provided in the studies, a thorough meta-analysis may help determine their relative influence within different systems. The exercise in this study was not intended to be a meta-analysis or a systematic review of the literature. Therefore, the quality of data provided for collation of information was not assessed (Cook *et al.*, 1997) as it would have been, had a systematic review protocol been followed (Hirst *et al.*, 2002). A systematic review highlights areas that are well proven from the data provided and, in theory, could determine whether these summary data are truly representative of the ability of the systems reviewed. The collation of this material did not lend itself to a systematic review process because many sources of information were published in the 'grey' literature and, because information was being gathered on system characteristics not just production results, all papers were considered. As already indicated, the amount of information gathered to populate the database varied in quantity, detail and quality, making a traditional meta-analysis to examine the influence of other variates an untenable task.

Additional key factors influencing production performance that are not evaluated are the abilities of the stockperson and the behaviour of the individual animal. Indirectly, the WDI rewards systems that allow the stockpersons to carry out their job effectively. Such characteristics involve the ability to easily separate piglets from their mothers, which allows the performance of certain husbandry and health management procedures that will impact on productivity. However, good stockpersonship is more than this and should incorporate skills, experience, conscientiousness and empathy. In theory, a good stockperson could make any system productive and welfare-friendly within the physical constraints of that system. The group systems may fail to translate their high welfare design scores into good production performance because of the constraints these systems place on the ability of the stockperson to do their job. For example, because the highly complex nature of the Family Pen system (Stolba and Wood-Gush, 1984; Kerr *et al.*, 1988) was based on the behaviour of animals under semi-natural environments, production performance should have been acceptable. In practice, piglet mortality and labour input and capital investment were unacceptably high (Kerr *et al.*, 1988). The complexity and detail may serve to achieve improved maternal behaviour (e.g. correct farrowing location), but may be difficult for supervision by the stockperson and particularly difficult for cleaning and maintaining hygiene. The designed pens are built on a much smaller footprint than the group systems, with sows and litters kept separately, making control and management an easier task, potentially contributing to good production results. The other crucial factor contributing to production performance is maternal behaviour. The welfare design assessment assumes that if certain design criteria are met, such as cues related to farrowing location (e.g. enclosure) or substrate to satisfy nest-building behaviour, then maternal behaviour will be good. However, as referenced by other authors, the success of these cues is by no means absolute (Edwards, 1996) and maternal behaviour is subject to individual variation (Thodberg *et al.*, 2002) and is likely to have a genetic component (Grandinson *et al.*, 2003). In small-scale studies, one problematic sow can easily negatively influence the production performance of a system that should, on paper, operate effectively. To a certain extent, confinement systems have the ability to minimise expression of this biological variability and poor stockpersonship and poor maternal behaviour may thus be less disastrous than in a loose-housed system. An alternative farrowing system needs to be robust to local circumstances and operate consistently for commercial uptake. This requires refinement of systems to ensure ease of management and operator safety and, unlike conventional systems, alternative systems lack a long history of trial and error to carry out these refinements and optimise working routines. In addition, further research into breeding for sows adapted to these conditions would most likely benefit performance. Genotype-by-environment interactions have been shown to influence piglet survival in loose farrowing systems (Baxter *et al.*, 2011b) and further investigations are required to define strategies for successfully breeding for better mothering ability, including appropriate reactions to both piglets and stockpersons. In countries where farrowing crates have been banned for a number of years, production results are more favourable and consistent (Andersen *et al.*, 2007; Weber *et al.*, 2009) and it is likely that, because the sows have been farrowing in loose-housed accommodation for several years, they have been indirectly selected for maternal and behavioural traits that optimise performance in this system.

Financial performance

Only limited data were available to evaluate the economic viability of alternative systems, and yet, commercial uptake depends not only on welfare and production performance but also on financial feasibility. As a result of the scarcity of data, investment costs had to be calculated based on the physical characteristics of each system as determined by the summary data provided and by consultation. Calculations for the cost of running systems, in terms of labour (hours per sow per year), were even more scarce and could not be estimated for all systems. The designed pens offered some of the most comprehensive data sets (e.g. Schmid, FATs – Dun, 1992; Weber, 2000; Weber *et al.*, 2007; Baumgartner, 2008; Werribee Farrowing Pen – Cronin *et al.*, 2000 and 2007) and demonstrated that well-thought-out engineering or 'clever' design could allow certain biological needs of the animals to be met without spiralling capital costs. For example, designed pens in this study cost approximately 17% more than conventional crates and, from the limited data available, had comparable labour requirements to conventional crates. These pens have costs for additional space and design complexity, but if this is offset by increased production performance in terms of piglet survival, weaning weight or sow rebreeding efficiency, then the capital investment should achieve an acceptable return rate. Certain systems could, in reality, require considerably less capital investment than a conventional crate and than the figures reported in this study. For example group systems such as the Swedish systems (Thorstensson and Ljungström) should be cheaper than installing a conventional crated system; crates themselves utilise more expensive components such as stainless steel, fully or partially slatted specialised flooring built above a slurry system, thus involving additional engineering and costs. In contrast, the Swedish systems could utilise an existing building, provide a microclimate with deep straw bedding, wooden nest-boxes and require solid manure removal only after each batch of farrowing. Although capital investment in group systems could be more economical than the present evaluation suggests, the cost of significant amounts of straw bedding and the high labour requirement suggest that these systems are likely to be financially untenable in many circumstances. Data on Thorstensson (Mattsson, 1996), Ljungström (Goetz and Troxler, 1995) and free access systems (Krieter, 2002) are limited to one study each and therefore require further investigation. Although not specified in all these studies, it is the additional manure handling that appears to incur the labour costs, a conclusion supported by researchers working in the Family Pen system (Kerr *et al.*, 1988), where the labour requirements are the highest from all the reported data. However, it is worth noting that lactation length is longer in this system and therefore such labour data are non-comparable.

No attempt has been made in this review to actually weigh economics against welfare. The data are simply presented for the reader to make judgements about system performance, both biological and financial. There are techniques described in other fields, such as environmental management, that attempt to tackle complex problems requiring consideration of numerous factors to make a judgement, such as using Multi-objective Programming or Multiattribute decision-making techniques (Hung *et al.*, 2006). These methods attempt to combine both quantitative and qualitative factors to make decisions on optimal outcomes, such as site location or management strategies (Hung *et al.*, 2006). Such factors are evident regarding the present aim; the WDI data could be used in a multiattribute decision-making model if combined with accurate data regarding the economic performance of systems. Herein lies the crux of the problem: the availability of data. Accurate data on all economic aspects of systems are lacking and, as already described, the WDI required certain assumptions to be made. For a full economic evaluation, there needs to be more data on labour inputs, energy, bedding, veterinary and feed costs and maintenance requirements, and an effort to measure the capital depreciation of the system and thus predicted long-term costs. There may also be other, less apparent, costs that are unique to individual systems. For example, an outdoor system compared with an indoor system could require additional costs, such as predator control, that should be taken into account for complete evaluation. Even with these constraints, there have been recent attempts by colleagues to use optimisation modelling techniques in combination with animal welfare science to test possible trade-offs between profit and welfare within alternative farrowing systems (Vosough Ahmadi *et al.*, 2011). Relationships or production functions between economic outputs (e.g. piglet survival) and welfare inputs (i.e. design criteria that could meet biological needs) were determined and these were used to model how increasing welfare inputs may influence economic outputs and vice versa. This study (Vosough Ahmadi *et al.*, 2011) served to highlight the main issues arising at the biological–economic interface and possible steps that could be used to address them and provides a potential tool to use when and if more data become available.

Future-proofing systems

From the evaluation of the systems described in this review, assessments of welfare and economic performance can be performed. However, in addition, it is important that these systems are robust to potential 'advances' in the way pigs are produced and what the international market wants from their product. For example, consumer requirements include a product that is energy efficient, with low environmental impact, that considers animal welfare, but still at a low cost. The environmental implications of different systems therefore merit further detailed consideration. Genetic selection pressure on economically important traits, such as litter size, will increasingly challenge the sow, her offspring, the skills of the stockperson and the farrowing environment in the future. The current and most comprehensive report on loose-farrowing systems demonstrates success, particularly with respect to piglet survival (Weber *et al*., 2007). These authors report a respectable 13% live-born mortality rate in both crates and loose-housed systems from a sample size of 44 837 and 18 824 litters, respectively. However, the average number born alive in both systems was 11.0. Increasing genetic selection pressure on litter size has resulted in the average number born alive in some European countries reaching 14.00 (e.g. Denmark – Fowler, 2009), with the European average being 12.09 (range 11.12 in Italy to 14.00 in Denmark – Fowler, 2009). Litter size is a known risk factor in pre-weaning mortality (Baxter *et al*., 2008), with increased litter size increasing the heterogeneity of the litter and the number of low-viability animals born that require extra care and extra managerial input. Therefore, all farrowing systems must consider how best to facilitate ease of management, particularly the so far overlooked yet crucial issue of operator safety, while still respecting the biological needs of the animals.

Conclusion

From the evaluation of welfare and economic performance of systems described in this paper, the designed pen appears to offer the best indoor alternative to conventional farrowing crates. However, it is important to make efforts to refine these systems as there are still concerns, particularly regarding safety and ease of operation, and robustness to variability in maternal behaviour. Research into physical attributes of the systems that can facilitate the former and biological strategies (e.g. breeding for better maternal behaviour) to target the latter are important on-going objectives. In addition, to futureproof systems for a developing pig industry and uncertain market, additional research is needed to determine the environmental impact of certain systems and their economic feasibility in a national and international market place.

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