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Review Alternatives to Farrowing Crates

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Section

1. Acknowledgements

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During the conduct of this project, Associate Professor Inger Lise Andersen and Professor Knut Bøe from the Norwegian University of Life Sciences visited the University of Sydney, Camden. Both scientists are internationally recognised for their applied research to develop and improve farrowing pen design for reduced piglet mortality and improved sow welfare. I would like to acknowledge these researchers, whose discussions assisted me and contributed to the development of this review.

2. Executive Summary

The animal welfare campaign against gestation stalls for sows serves as a reminder to industry of the pressure for practice change that can be imposed by lobby groups. The banning of farrowing crates in Australia is on the agenda of the animal welfare groups. Industry thus needs to prepare for this eventuality by consolidating information on the alternatives to crates and seeking advice on practical strategies to prepare industry for the eventuality that farrowing crates are banned. The objectives of this project were to evaluate sow and litter performance in farrowing crates compared to non-crate systems reported in the literature and to identify gaps in knowledge to recommend how the Australian pig industry could proceed to adopt practical non-crate farrowing/lactation systems.

A number of criteria are relevant to assist the evaluation of non-crate compared to crate farrowing systems. For this project, information was sought under the categories of piglet measures, sow measures, capital costs and operating costs. Sows and litters are husbanded under a range of accommodation systems, which may be located either indoors or outdoors, and with sows kept either individually or as part of a group. Sows kept individually under indoor conditions may be "restrained" in a farrowing crate or "loose" housed in a farrowing pen. Another indoor option is the group farrowing pen system, while still other combination systems exist, for example, involving housing in farrowing crates then relocation to group lactation pens. Outdoors, sows may be maintained in paddocks individually (rare) or in groups. In each farrowing paddock, at least one farrowing hut is provided per sow due to farrow in the group.

A major benchmark of farrowing accommodation systems is the number of piglets weaned. Piglet survival to weaning is the relationship between the total number of piglets born, less piglet mortality due to all causes including stillbirth. Piglet mortality may be expressed as either the proportion of deaths of total born in the litter, or of live born (after adjusting for fostered piglets in the litter). Piglet mortality as a proportion of live born pigs is more commonly quoted in research reports. However, studies should include the occurrence of stillbirths, as stillbirths constitute a significant proportion of reproductive wastage, and it is likely that relationships exist between conditions in the uterine environment, pre-farrowing sow behaviour, the birth process and the occurrence of stillbirth. Further, these variables are also likely to influence the viability of neonates and thus influence preweaning mortality.

"Loose" Farrowing Pens Compared to Farrowing Crates

More than 30 trials have been reported since the mid-1960s, in which piglet mortality was compared for litters of individually-housed sows in "loose" pens compared to farrowing crates. In more than half of the reported trials (56%), piglet mortality was lower in farrowing crates than loose pens. In 31% of reports, piglet mortality was lower in loose pens than farrowing crates, while in 14% of reports the difference was 0.5% or less, which may be considered similar. In addition, recent surveys from Switzerland indicate that after a decade of commercial use of "loose" farrowing pens, piglet mortality in pens was equivalent to that reported for farrowing crates.

Indoor Group Farrowing Systems

There have been fewer reports of trials investigating sow and piglet performance in indoor group farrowing systems. In general, piglet mortality has been reported to be higher in group farrowing pen systems than farrowing systems involving individually-housed sows in crates or pens. Nevertheless, the group farrowing pen system involves relatively low capital investment, and research to improve production (i.e. increase the number of piglets weaned) is likely to continue.

Outdoor Farrowing Systems

Due to the low capital investment and the perceived welfare benefits of pasture-based (extensive) pig production systems, outdoor farrowing has increased in popularity over the last 30 years. Sows are generally housed in groups, although a small number of trials have concluded that litters of sows housed in individual paddocks had lower preweaning mortality than sows farrowed outdoors in groups. Trials reporting piglet mortality in outdoor compared to indoor systems (mainly in farrowing crates) are equivocal as to which system is better in relation to piglet survival.

New indoor, individual farrowing pen systems for sows and litters require extra floor space and construction complexity compared to crates. Thus, greater capital investment will be required, so it is important that the number of piglets weaned per sow is increased to ensure that returns on investment are maintained. While this may not be achievable, a possible solution to maintain economic viability involves the trade-off between a lower capital investment system and fewer piglets weaned, that is, accepting higher piglet mortality.

The literature indicates that comparable levels of piglet survival, one of the main economic and welfare parameters for evaluating alternatives to farrowing crates, have been achieved in most non-crate farrowing systems. The lack of consistency in reporting "good" findings suggests we lack understanding of the factor(s) within the "successful" farrowing systems that contributed to their success. A key difference between farrowing sows in a confined, crate environment compared to a "loose" pen with bedding, is that the combination of space and bedding stimulate the sow's natural pre-farrowing behaviour. If we provide the sow with a stimulating (enriched) environment, then it is essential to provide the sow with an appropriate space in which to farrow, that also contains design features to promote piglet survival. Further, the sow and litter need to be managed correctly to identify problems and to rectify them as soon as possible.

Gaps in Knowledge before the Australian Industry Proceeds to Adopt Non-Crate Systems

How to select and train stockpeople to manage sows and litters in non-crate systems?
How much straw to provide under Australian (summer) conditions?
What is the optimum pen size in a non-crate system?
Can the relationship between farrowing behaviour and piglet viability be enhanced?
Is there a relationship between pre-farrowing nest-building behaviour and post-farrowing careful behaviour by the sow?
What is the optimum piglet weight at birth in farrowing pens?
How is the development of the foetal pig related to piglet viability and behaviour at birth, and survival to weaning in non-crate systems?
How to design pens to prevent sows and piglets from dunging in the "wrong" location?
How to design and manage farrowing pen systems under hot climatic conditions?
How to get the piglets to use the safety zones sooner in farrowing pens?
What is the efficacy of genetic selection for piglet survival in non-crate systems?

3. Background to Research

The rapid expansion in pig production in the years following World War II in Europe has been well documented (Thornton, 1990). Post-war society needed a reliable source of cheap, safe food (and especially protein) and the pig industry was able to respond to this opportunity. For example, the United Kingdom Veterinary Investigation Service (1959) stated that one of the features of post-war agriculture in the UK was the expansion of the pig industry, with the number of pigs kept on agricultural holdings in England and Wales increasing by 250% and the contribution of the pig industry to the UK livestock economy rising by 550% between 1946 and 1958.

While these changes could not have occurred without some degree of intensification of pig production, pig growth and reproduction were nevertheless (relatively) inefficient compared to the pig's genetic potential. The expansion of "pig science", which I loosely define here as the application of scientific disciplines to improve pig production, from the 1960s onwards has had a very large impact on the world-wide development of the pig industry as a specialised agribusiness, rather than a sideline income earner to dairy (milk) or grain production, as occurred in Australia prior to about 1970.

However, in the decade following WWII, the UK Veterinary Investigation Service (1959, 1960) expressed concerns due to "heavy wastage in the pig industry due to disease and from other causes associated with management which occurred during the suckling period". Sows were typically "loose" housed in straw bedded pens at farrowing and during lactation. Piglets were weaned at 8 weeks of age. The development of farrowing crates, constructed within better designed, insulated buildings, with localised heating for piglet creeps and perforated floors for improved drainage and better hygiene, addressed many of the productivity and health deficiencies of loose farrowing systems. Pig farmers were thus helped in their objective of reducing piglet losses, but an associated increase in capital investment was required to construct specialist farrowing accommodation to achieve this important goal. To minimise the investment cost, space per sow and litter in farrowing accommodation needed to be minimised. Coincidental with these developments, genetic selection for larger, heavier sows that produced larger litters of bigger piglets was also occurring.

The construction of intensive livestock farming practices resulted in questioning of the impact of husbandry and housing methods on animal welfare (e.g. the Brambell Report – Brambell et al., 1965). While Brambell et al. (1965) expressed opposition to stall- and tether-housing for pregnant sows, they did not object to the close confinement of sows in farrowing crates. Close confinement "only occurred during parturition and the succeeding few days and was in the interests of the piglets".

Farrowing crates can improve the welfare of neonatal pigs by providing warmth in a restricted space and limiting the risk that neonates wander away from the sow (or the source of warmth), become chilled and die from either starvation or overlying. Farrowing crates and the concomitant lack of (straw) bedding however, restrict the ability of sows to perform "normal" pre-farrowing behaviours such as nest-site selection, nest-building activity and bonding with the piglets, and thus have been criticised on welfare grounds (viz. RSPCA Five Freedoms Concept).

The removal of the farrowing crate structure from farrowing pens may result in higher piglet mortality, including increased piglet deaths due to crushing by the sow. Over the last 30 years therefore, researchers have been attempting to (re-)develop non-crate farrowing systems that (1) address the perceived behavioural deficiencies experienced by sows in the peripartum period, (2) promote piglet survival and (3) are economically viable and practical to operate for pig producers.

The objectives of this review are to evaluate sow and litter performance in farrowing crates compared to non-crate systems reported in the literature and identify gaps in knowledge to recommend how the Australian pig industry could proceed to adopt practical non-crate farrowing/lactation systems.

A number of criteria are relevant to assist the evaluation of non-crate compared to crate farrowing systems. For this project, information was sought under the following categories:

- Piglet measures – survival/mortality, morbidity and growth.
- Sow measures – health and fitness, feed intake, breed and genetic line.
- Capital costs – capital investment per unit area and per sow and structural costs.
- Operating costs – energy use, labour, bedding, feed, maintenance and repairs.

It was assumed that pig producers would consider similar categories of information when deciding whether to change from a conventional farrowing crate system to a non-crate alternative system, such as an indoor farrowing pen system. The identification of gaps would facilitate the development of research priorities to provide further information to improve decision-making by producers.

Thus, the objectives of this review are to evaluate sow and litter performance in farrowing crates compared to non-crate systems reported in the literature, and to identify gaps in knowledge to recommend how the Australian pig industry could proceed to adopt practical non-crate farrowing/lactation systems.

4. Objectives of the Research Project

4.1 Objective 1: Evaluate Sow and Litter Performance in Farrowing Crates Compared to Non-Crate Systems Reported in the Literature

4.2 Objective 2: Identify Gaps in Knowledge to Recommend how the Australian Pig Industry Could Proceed to Adopt Practical Non-Crate Farrowing/Lactation Systems

5. Introductory Technical Information

The Australian pig industry recognises that alternatives to farrowing crates need to be identified and evaluated, should the community, markets and/or regulators/legislators apply pressure to prohibit or limit the use of farrowing crates by industry. Thus, this report addresses APL's specific priority to "Assess the effectiveness of alternative production systems and management practices."

During the 1990s, Australian Pork Limited's predecessor the Pig Research and Development Corporation (PRDC) co-funded a series of research projects with Greg Cronin at DPI Werribee to develop and evaluate a practical farrowing/lactation pen. The pen that was developed, the so-called "Werribee Farrowing Pen", developed from Cronin's fundamental research conducted between 1986 and 1990 on the relationships between the structural and social environments, maternal and neonate behaviour and piglet survival and growth. Towards the end of the 1990s, on-farm trials of the Werribee Farrowing Pen were conducted to evaluate the performance of sows and litters in pens compared to conventional farrowing crates. An important finding was that piglet mortality to weaning was similar in farrowing crates compared to Werribee farrowing pens.

Before the development of farrowing crates, loose pens were widely used for farrowing sows (Harris 1906). Piglet mortality was high and pig producers often supervised farrowing to improve piglet survival. In the 1940s the farrowing crate concept began to gain recognition and producers found that mortality could be reduced with the use of crates (Phillips and Fraser, 1993). By the mid-1970s, the farrowing crate had become the predominant form of housing for farrowing/lactating sows. However, the level of restriction placed on sows was considered a risk to sow welfare by animal ethologists. Sows are motivated to perform species-specific behaviour prior to farrowing, which is thwarted (frustrated) through the restriction of movement imposed by the crate (0.5 – 0.6 m wide x 1.8 – 2.0 m long sow stall) and the lack of bedding material provided.

In an unrestricted environment, the pre-partum sow leaves her herd, and may travel up to 6 km while she seeks a protected, isolated site for farrowing. At the site she digs a shallow hole through rooting and pawing actions. Vegetation is gathered and placed in the hole to line the earth base of the nest. Additional material is gathered and added to the nest. In colder conditions, more vegetation is added (Jensen 1986, 1989, 1993). The sow then burrows into the nest for parturition. Nest-building is at least partly under the control of endogenous hormones (Lawrence et al., 1992) in the pig, and the housing of sows in farrowing crates without straw bedding results in frustration of nest-site selection and nest-building behaviours, which was assumed to be associated with poor welfare.

The debate on the welfare of intensively housed pigs (in general) also focussed attention to the negative features of the farrowing crate. Under the Five Freedoms Concept, sows confined to farrowing crates 'suffered' because they were unable to perform 'natural' behaviour such as nest-building, etc. One outcome of the animal welfare criticisms has been the development of a number of non-crate farrowing systems.

Removal of the crate (stall) component of the farrowing pen environment increases the opportunity for sow movement in farrowing pens compared to farrowing crates. The opportunity for sows to move about however, has signalled a number of potentially important pig and human welfare and production problems that also need to be considered before commercial pig producers replace existing farrowing crates with an alternative farrowing/lactation system. Parameters that are typically considered when comparing conventional farrowing crates with alternatives are the survival, health and growth of piglets, since the number of piglets weaned and the efficiency of growth (feed conversion) are important factors determining farm profitability. Other factors must also be considered, such as sow health, productivity and retention in the herd. By modifying the method of housing the sow, to one in which the sow is not restrained, requires reassessment of the human safety issues, stockperson skills and competencies. By changing the type of floor surface (perforated to solid), increasing pen size and altering the structural design of the space and potentially introducing bedding, labour inputs for cleaning and maintenance may increase. These parameters need to be measured in terms of work load and ease of management by stockpeople. Finally, farmers need to know the capital investment required to establish any new housing system, and the cost of operating the housing system.

The PRDC, predecessor of Australian Pork Limited (APL), co-funded research in Victoria commencing in 1985/86 (DAV 55P, DAV 92P, DAV 114P) investigating non-crate farrowing by sows and piglet survival. The research was enabled because PRDC funded the construction of a 12 x 12 m experimental farrowing shed at Werribee. In Project DAV 55P a very important research finding identified that the provision of extra space for piglets, such as in a “loose” or “open” farrowing pen, could in fact result in increased piglet mortality (Cronin and Smith, 1992a; Cronin et al., 1994). The latter research also showed that enriching the farrowing environment through the addition of straw bedding did not necessarily improve piglet survival – the space available for the new born piglets was critical, especially in cool ambient temperatures.

In Project DAV 92P a potential loose farrowing system for individually-housed sows was developed. The farrowing/lactating pen, which was named the Werribee Farrowing Pen, was based on research findings from Project DAV 55P and other farrowing research from overseas. The Werribee Farrowing Pen consisted of two distinct areas within a rectangular pen. These areas were referred to as the 'nest' and the 'non-nest' areas. The rationale for developing the Werribee Farrowing Pen was to provide a research tool in which the relationships between environmental enrichment (stimulation), sow and piglet behaviour and piglet survival and growth could be better investigated, without the confounding effect of extra space causing higher piglet losses. Project DAV 92P only involved the use of primiparous sows, as the Werribee sow herd was exclusively a gilt herd in those years. Nevertheless, the research showed that piglet survival in a loose farrowing/lactation pen was equal to that achieved in farrowing crates.

In PRDC-funded project DAV 114P (Cronin, 1997), research continued on the practical application of the Werribee Farrowing Pen as an alternative to the farrowing crate. The research focussed on the design of the nest area of the pen, as this area was considered more relevant to piglet survival than the non-nest area. While a number of key design features were incorporated in the nest area, these features would be of no value unless the sow farrowed in the nest area. Thus, the orientation and structure of the nest area were designed to be attractive to the sow as her preferred site for farrowing.

In its prototype form, the nest area of the Werribee Farrowing Pen measured 2.4 m wide and 1.8 m deep. The floor of the nest area was solid concrete, with a 3-4% slope towards the front of the pen for drainage. It was recognised that the success of the Werribee Farrowing Pen as an alternative to the farrowing crate, depended on a number of practical factors such as:

1) The sow must farrow in the 'nest' area rather than the ‘non-nest’ area of the pen.
2) Piglet survival and growth should not be disadvantaged in the pen compared to conventional farrowing crates.
3) The total spatial requirement, and costs of fabrication and installation, should be equivalent to, or preferably less than, those for conventional farrowing crate systems.
4) The management of the pen system, and the husbandry of animals in the system, should neither be more complicated nor onerous than crate systems.

During the conduct of PRDC Project DAV 114P (Cronin, 1997), the research piggery at Werribee expanded and the sow herd structure and management changed. The sow herd became a multiparous herd and a new, larger farrowing shed was constructed from funds provided via the University of Melbourne, which had recently closed its pig research facility at Mt Derrimut. Multiparous sows were now included in experiments investigating piglet survival in farrowing pens. The importance of farrowing pen width had been identified, but this was based on the earlier experiments that had utilised gilts (primiparous sows). Unfortunately, no further funding was achieved from 1999 to continue the development of the Werribee Farrowing Pen design.

In 2002, DPI Victoria funded a study tour to Switzerland by Greg Cronin to visit Dr Roland Weber, an agricultural engineer at the Swiss Federal Research Station for Agricultural Economics and Engineering, Tänikon. Dr Weber had conducted research over 20 years on the development of farrowing pen systems. The importance of having commercially-viable farrowing pen designs available for Swiss pig producers was substantial, because farrowing crates were due to be banned in Switzerland from the end of June 2007. In addition, farrowing pens installed from July 1997 had to provide at least 4.5 m^2 for the sow, which basically precluded producers from installing any form of farrowing crate. Dr Weber’s research had almost exclusively been reported in the German-language literature, which resulted in general non-awareness, particularly by English-speaking researchers. Due to the work of Dr Weber and others in Switzerland, commercially viable farrowing pens are available and can be purchased from various Swiss manufacturers. The link formed between Roland Weber and Greg Cronin at that time provided the opportunity for information exchange between the Swiss and Australian researchers involved in R&D on non-crate housing for farrowing/lactating sows. Subsequently, a research collaboration has been established between Greg Cronin (now at the Faculty of Veterinary Science, University of Sydney) and Associate Professor Inger Lise Andersen and Professor Knut Bøe from the Norwegian University of Life Sciences, who are active in the continued development and evaluation of non-crate housing systems for farrowing/lactating sows. Due to this collaboration, a research facility incorporating the Norwegian UMB farrowing pen system has been established at the University of Sydney pig unit at Camden.

6. Research Methodology

The project involved reviewing the literature on the principles of design and management of non-crate farrowing systems. The review included descriptions of the different non-crate housing systems and an evaluation of the performance of sows and litters between the different types of system and conventional farrowing crates. Incorporated in this report is information from the published literature as well as from unpublished reports by Australian and international researchers.

Assessment criteria that were initially considered for the evaluation component of the project included:

- Piglet measures - survival/mortality, morbidity and growth
- Sow measures - health and fitness, feed intake, breed, genetic line
- Capital costs - capital investment per unit area and per sow, structural costs
- Operating costs - energy use, labour, bedding, feed, maintenance and repairs

However, relatively little objective information is available on the capital costs, labour costs or ease of operating loose farrowing/lactation systems. Information on the human perspective was considered important due to the specific nature of labour inputs, e.g. tasks such as pen set-up prior to sow entry, sow feeding, pen cleaning and animal handling, and the potential OH&S issues associated with the tasks. Anecdotal comments were sought from stockpeople towards non-crate systems.

Finally, gaps in knowledge have been identified and recommendations for actions to build a research programme to resolve the gaps are provided.

7. Results and Discussion

7.1 Objective 1: Evaluate Sow and Litter Performance in Farrowing Crates Compared to Non-Crate Systems Reported in the Literature

Descriptions of Different Farrowing Systems

A number of reviews have been published which describe the various types of farrowing accommodation developed over the years by the pig industry (Phillips and Fraser, 1993; Edwards and Fraser, 1997). It is not the purpose of this project to provide a detailed description of the different alternatives to farrowing crates.

Figure 1 represents the main combinations of farrowing accommodation types for sows: Housing may be either indoors, outdoors or a combination of these such as a straw-yard, in which the sow and litter have access to both indoor and outdoor components of a pen. Sows may be accommodated either singly or in a group. Sows may be "confined" in a farrowing crate or "loose-housed" in a pen or paddock. "Loose housing" was defined by Phillips and Fraser (1993) as an enclosure in which the sow can turn around freely. In some farrowing systems, the level of sow confinement may be reduced as lactation progresses, with sows being transferred from crates to pens, or even to group lactation pens.

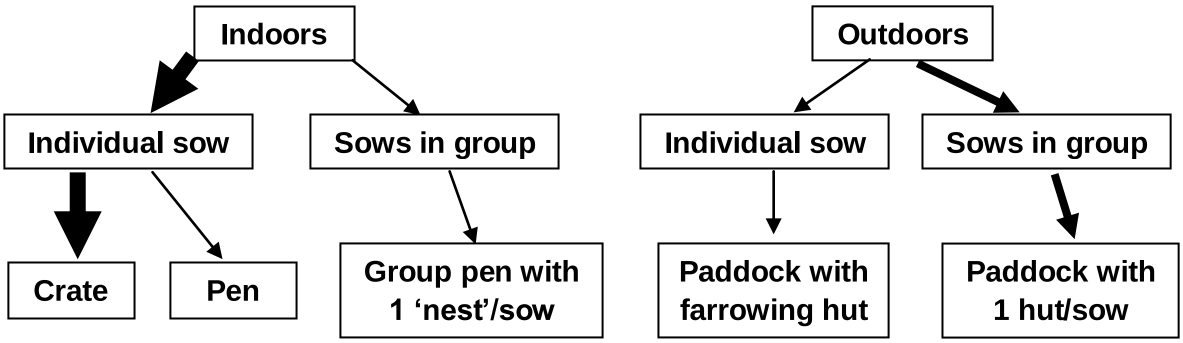

Figure 1: Farrowing accommodation types for sows and litters. The thickness of arrows suggests the relative occurrence of the different combinations.

Phillips and Fraser (1993), Edwards and Fraser (1997) and Marchant (1997) amongst others provide descriptions of farrowing systems and the changes in design and management of farrowing accommodation that have occurred over time. In addition, two indoor group-farrowing/lactation systems have been described by Halverson et al. (1997), while Thornton (1990) and McGlone (1997) describe outdoor systems and farrowing hut designs.

Performance Indicators

Assessment criteria that were considered for the evaluation component of the project included:

- Piglet measures - survival/mortality, morbidity and growth
- Sow measures - health and fitness, feed intake, breed, genetic line
- Capital costs - capital investment per unit area and per sow, structural costs
- Operating costs - energy use, labour, bedding, feed, maintenance and repairs

Literature that was found to provide information under these criteria have been collated and are reported here.

Piglet Measures

The main piglet profit indicator is the number of piglets weaned per sow. Live weight gain of piglets is also important, but considered secondary to the number of piglets weaned. Number weaned will be influenced by the genetic and reproductive potential of the animals in the herd, including factors such as the rates of ovulation, fertilisation, conception and embryo survival, piglet development *in utero* and piglet birth weight and viability. The number of piglets weaned will be affected by piglet mortality, including stillbirths. Piglet growth may be affected by piglet birth weight and viability, sow milk production, health status of the sow and piglet, shed hygiene and litter size. While environmental conditions influence sow and piglet behaviour and may impact on many of the factors listed above, the knowledge, skill and motivation of the stockperson to monitor sow and piglet performance around farrowing and during lactation, and to respond in a timely manner to potential adverse situations, cannot be emphasised enough.

Thus the major focus of research has been on perinatal mortality in the pig. A detailed review by Edwards (2002) examined perinatal mortality under commercial conditions and identified solutions which have been, or might be, implemented to improve piglet survival. Edwards (2002), and earlier researchers in this area such as English and Morrison (1984), emphasised the importance of piglet vitality in the immediate post-partum period as a key factor to address for reducing piglet losses. A number of other reviews and papers have also been published on this topic in the past decade (Grandison et al., 2002; Herpin et al., 2002; Quiniou et al., 2002; Knol et al., 2002; Mesa et al., 2006; Baxter et al., 2009).

The Causes and Timing of Piglet Mortality

High level of piglet mortality has been an historical problem for pig producers (e.g. Harris, 1906). A major reason why farrowing crates were developed was as an attempt to reduce piglet deaths before weaning (Thomson et al., 1960). Based on the records from a large number of UK pig herds, Thomson et al. (1960) reported that piglet mortality was 27% (range 22-34%) and that most deaths occurred soon after parturition. Many studies of the causes and timing of piglet losses have since been reported (e.g. Veterinary Investigation Service, 1960; Sharpe, 1966; Fahmy and Bernard, 1971; Glastonbury, 1976, 1977; Spicer et al., 1986; Svendsen et al., 1986; Edwards et al., 1994) and there have been many reviews of the literature (e.g. Edwards and Fraser, 1977; English and Morrison, 1984; Cronin et al., 1989; Edwards, 2002; Cutler et al., 2006). In summary, the majority of piglets die within the first three days of life (including stillbirths) and the main causes of neonatal loss are intra-partum stillbirth/weak/non-viable, crushing by the sow and chilling/starvation.

Comparisons of Piglet Mortality in Different Farrowing/Lactation Systems

Reviews of the causes and timing of piglet mortality in different farrowing/lactation systems occur in the literature from time-to-time. For example, Edwards and Fraser (1997) reviewed published experiments and surveys involving comparisons of farrowing crates versus "open" pens for individual sows. A significant cause of death in pen systems was crushing by the sow. Piglet deaths were reported to be higher in farrowing pens in 8 of 8 experiments and 3 of 4 surveys published between 1966 to 1994. Compared to studies on the causes and timing of piglet deaths in indoor farrowing/lactation systems, there are fewer reports for outdoor systems (Edwards et al., 1994; Baxter et al., 2009), and still fewer for indoor group farrowing systems (Marchant et al., 2000).

Piglet Mortality in Farrowing Crates vs. Pens with Individual Sow Housing, Indoors

The results of trials reporting piglet mortality in litters of sows housed individually indoors, comparing farrowing crates and farrowing pens, were collated from the literature (Table 1). Of the 36 comparisons listed in Table 1, mortality was lower in farrowing crates than farrowing pens for 64% of comparisons. An alternative perspective on the data is that, for 36% of comparisons, piglet survival was better in farrowing pens than crates.

Recently, Edwards et al. (2010) reported that piglet mortality in the new PigSAFE farrowing system was 14.9% of born alive (based on 152 litters farrowed). Although comparative data for piglet mortality in farrowing crates was not presented by Edwards et al. (2010), the performance of the farrowing pen system is being evaluated against the UK/EU benchmark of 12.8% pre-weaning mortality.

Surveys of Piglet Mortality in Indoor Systems for Individually Housed Sows

Survey data comparing piglet mortality in farrowing crates and farrowing pens have also been reported. Edwards and Fraser (1997) reported four farm surveys published between 1979-1982 and mortality was higher for litters in pens than crates in three of the four surveys; in the fourth survey by Gustaffson (1982; cited by Edwards and Fraser, 1997) involving data from 72,507 litters, piglet mortality of 18.7% was reported for both crate and pen systems. Recently, Weber et al. (2007) reported the findings of data mining of the Swiss UFA2000 sow recording scheme, in which records of piglet mortality in farrowing crates were compared to "loose" farrowing pens. Piglet mortality was the same in the two systems, at about 12.8% of live born. Subsequently, Weber (2009) surveyed the records for piglet mortality on Swiss pig farms and reported that piglet mortality was 12.1% for farms with farrowing crates (482 farms) and "loose" farrowing pens (173 farms). The proportions of piglet deaths due to crushing by the sow in the two systems were 37% in crates and 45% in "loose" pens. Weber (2009) identified three important factors influencing piglet mortality that required further investigation: (1) litter size at birth, (2) birth weight and (3) farrowing pen size.

Neonatal Viability

According to Weber (2009), piglets that are crushed are on average lighter weight at birth than piglets that survive to weaning (crushed: 1.17 kg vs survived: 1.42 kg). Underweight piglets may be less vital. Whether underweight (less viable?) piglets are more likely to be found lying scattered about in the sow zone, instead of grouping with the other piglets, including in the creep area, is an important question that needs to be addressed in loose housing systems?

A number of reviews have identified the importance of neonatal viability (e.g. English and Morrison, 1984; Edwards, 2002). The possibility of keeping less-viable piglets alive to day 4 of lactation through intensive care practices has been demonstrated. For example, Cronin (1993) reported work conducted by Houwers et al. (1992) in the Netherlands. Sows were placed in elaborate 'polyclinic' crates for farrowing, and piglet mortality in the first 3 days postpartum was close to zero. On day 4 the sows and litters were transferred to lactation pens in an 'integrated' group housing system. Piglet mortality from day 4 to weaning was 11.3% of born alive, indicating that the advantage of keeping effectively every piglet alive through an intensive housing and husbandry regimen was lost thereafter. Although Houwers et al. (1992) did not speculate on this point, it is possible that at least some of the piglets that were kept alive during the first 3 days of life through intensive husbandry methods were destined to die before weaning. Perhaps the piglets were "less viable"?

Farrowing Space/Farrowing Pen Size

Other surveys have also been reported which focus on performance in farrowing pens. For example, Fahmy and Bernard (1971) analysed farrowing records from a ten year period for litters born in farrowing pens. Overall piglet mortality was reported at 17.6% of live born and pen space ranged from about 5.3-9.4 m^2. However, while the authors conducted detailed analyses of the timing and causes of piglet death, and investigated the relationships between piglet birth weight, litter size, birth weight variability and inbreeding, and survival to weaning, they did not examine the relationship between farrowing pen size and mortality. Recently, Weber (2009) reported data from Swiss pig industry surveys which suggested a tendency towards an inverse relationship between farrowing pen size and piglet mortality (Fig. 2).

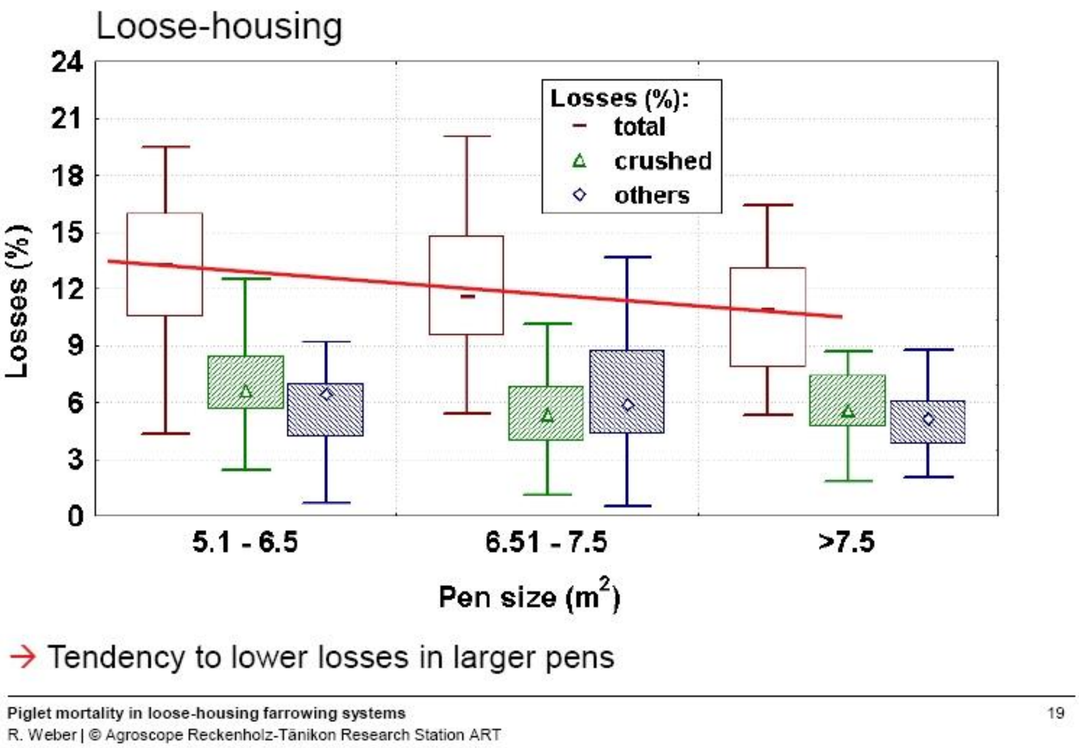

Figure 2: The inverse relationship between pen size and piglet mortality reported by Weber (2009) based on Swiss pig industry survey data

Table 1: A summary of findings from indoor housing trials, comparing piglet mortality in litters from farrowing crates and farrowing pens. Unless otherwise indicated, percentage values shown are for deaths of live born piglets

Source	No. litters	Mortality parameter Crates	Pens	Notes / comments (PWM: preweaning mortality with range of values across pen treatments)
Robertson et al. (1966)	150	15.5%	21.3%	mortality to 3 wks; outdoors during gestation
Devilat et al. (1971)	46	10.2%	13.5%	mortality to 2 wks; no bedding in pens
Svendsen & Andréasson (1980)	211	15.0%	12.6%	mortality to 3 days, includes stillbirths
Svendsen et al. (1986)	702	4.4%	6.5%	mortality due to crushing
Gravås (1982)	76	16.8%	13.3%	mortality to 6-7 wks
Gravås (1982)	84	16.1%	15.3%	mortality to 4 wks
Collins et al. (1987)	118	12.0%	12.4%	pens had a sloping floor
McGlone & Morrow-Tesch (1990)	20	10.8%	27.1%	horizontal floors in crates and pens
McGlone & Morrow-Tesch (1990)	20	17.2%	9.1%	sloped floors in crates and pens
Cronin & Smith (1992a)	64	10.7%	16.8%	half the sows had straw bedding
Cronin & Smith (1992b)	18	19.8%	8.2%	the pen treatment had straw
Rudd et al. (1993)	20	14.0%	37.0%	summer farrowings
Rudd et al. (1993)	20	14.0%	13.0%	winter farrowings
Blackshaw et al. (1994)	16	14.0%	32.0%	3 pigs/litter more in pens than crates
Lou & Hurnik (1994)	64	15.0%	15.4%	the 'pens' were ellipsoid farrowing crates
Cronin et al. (1996)	96	9.9%	8.8%	primiparous sows only
Hesse et al. (1996)	310†	16.6%	11.0%	† : piglets born rather than sows or litters
Cronin (1997)	60	8.5%	14.3%	2 pen designs (PWM: 12.5%-16.2%)
Weber (1997)	217	15.7%	14.4%	2 pen designs (PWM: 13.5%-15.2%)
Cronin (1998)	89	13.4%	16.7%	4 pen designs (PWM: 11.2%-24.4%)
Jarvis et al. (1998)	31	10.3%	15.0%	deaths of total born; all were gilts that were catheterised under general anaesthetic
Bradshaw and Broom (1999)	18	0.5‡	2.0‡	‡: data reported as median deaths/litter
Cronin et al. (2000)	146	17.5%	15.3%	multiparous sows
Marchant et al. (2000)	28	15.2%	24.8%	
Jones et al. (2003)	830	13.5%	20.1%	
Jervis et al (2005)	122	5.6%	12.2%	deaths due to crushing by sow
Moustsen (2006)	453	11.7%	11.4%	
Moustsen (2006)	339	11.3%	11.6%	
Cronin (2007)	85	16.5%	19.7%	multiparous sows
Cronin (2007)	66	16.6%	15.7%	primiparous sows, selected for non-crushing
Verhouvsek et al (2007)	22	10.1€	9.1€	€: number of piglets weaned/litter
Loudon (2008)	312	6.2%	10.2%	all seasons
Loudon (2008)	234	5.9%	7.9%	summer data omitted

Pedersen & Jensen (2008)	17	6.0%	19.0%	primiparous sows; placed in treatments on day 114
Pedersen & Jensen (2008)	20	14.0%	18.0%	multiparous sows; placed in treatments on day 114
Kutzer et al. (2009)	113	1.49♠	1.29♠	♠: deaths/litter to day 10 of lactation

Piglet Mortality in Indoor Group Farrowing Pen Systems

The management of sows farrowing in groups indoors is seen by many as problematic. Nevertheless, a number of indoor group farrowing systems have been developed. Amongst the earliest researchers who investigated key behavioural features for sows in the farrowing environment were Stolba and Wood-Gush (1984). Fundamental research commenced in 1978 at the Edinburgh School of Agriculture on domestic Large White pigs released into "the Edinburgh Pig Park". The behaviour of the pigs was studied in detail over many years, through reproductive cycles, to investigate the unrestricted behaviour of pigs. One outcome of this research programme was the development of the 'family pen system' for pigs. Other group farrowing systems were also developed around the same time. For example, two Dutch systems were developed which were labelled "integrated" (Buré and Houwers, 1990) and "multi-phase" systems (van Putten and van de Burgwal, 1990), respectively. In both systems the sows remained in groups throughout gestation and farrowing/lactation. Sows wore transponder collars which gave them access to feed from an electronic feeding station, and in the "integrated" system, access to different compartments in the pig shed. Since then, a number of other group farrowing systems have been developed (Table 2).

Table 2: A summary of findings from trials reporting piglet mortality in litters from indoor, group farrowing systems. Unless otherwise indicated, percentage values shown are for deaths of live born piglets

Source	No. of litters or herds†	Indoor group; Piglet mortality	Comparison(s)	Notes / comments Group system name
Arey and Sancha (1996)	48	28.5%	25.2% in crate	Edinburgh family
Baxter (1991)	40	12%		Freedom farrowing
Nash (1993)	34	25%		Freedom farrowing
Bøe (1994)	15†	16.3%	Norway herd average: 14.4%	Commercial farms using integrated systems
Kavanagh (1995)	>500	19.2%		Free-access farrowing nest system
Halverson et al. (1997)	49	14.5%		Västgötmodellen
Jungclaus and Jungclaus (1997)	1†	31.4%	Crates in local region:11.2%	Västgötmodellen
Honeyman and Kent (1997)	28	18.4-24.2%		Multiple commercial farms; Västgötmodellen
Marchant et al. (2000)		25%	Crates: 13%	
Dybkjaer et al. (2001)	60	14.1%	Crates: 9.4%	to day 11 of lactation
Dybkjaer et al. (2003)	72	10.9%		to day 11 of lactation
Kutzer et al. (2009)	230	1.58 deaths	Individual pen: 1.29 Crate: 1.49 deaths	Deaths/litter to day 10
Li et al. (2010)	421	22.6%		Range 18.6-30.0%
Payne & Cronin (2010)	1†	28.4%		Västgötmodellen in an Ecoshelter

Piglet Mortality in Outdoor Farrowing Systems

There has been a resurgence of interest in the commercial farming of sows in outdoor systems. Table 3 presents piglet mortality data from reports investigating piglet mortality in outdoor systems. The majority of systems involve managing sows in groups with one farrowing hut provided per sow in each farrowing paddock. However, there have been a few investigations of outdoor systems in which sows are kept singly in paddocks.

Table 3: A summary of findings from trials investigating piglet mortality in litters from outdoor farrowing systems. Unless otherwise indicated, percentage values shown are for deaths of live born piglets

Source	No. of litters or herds†	Outdoor group	Outdoor single	Indoor	Notes / comments
Andersen (1993)	321		12.2%	9.7%	
Edwards et al. (1994)	105	20.0%‡			17.9% of deaths were stillbirths
Berger et al. (1995)	64†	20.4%			
Edwards & Zanella (1996)	293†	17.8%		19.1% ‡	MLC 1995 data
Berger (1996)	102,814	16.8%		12.2%	1995 data
Edwards & Zanella (1996)	412†	18.6%		17.7% ‡	Easicare 1995 data
Higgins & Edwards (1996)	47	23.1%	14.9%		
Berger et al. (1997)	747,548	21.1% ‡		17.4% ‡	1990-1994 data
Herskin et al. (1998)	36	10.3%			
Petrocelli & Burgueno (1998)	1174	17.3%			Individual producers
Petrocelli & Burgueno (1998)		22.2%			Co-operative farm
Kongsted & Larsen (1999)	54†	18.3% ‡		18.7% ‡	1998 data
McGlone & Hicks (2000)	96	19.7%			American hut design
McGlone & Hicks (2000)	29	11.2%			English hut design
Honeyman & Roush (2002)	206	6.0%			USA; primiparous sows only, farrowed in Sept over 4 years
Wülburs-Mindermann et al. (2002)	99	1.5		1.3	reported as piglet deaths/litter
Johnson & McGlone (2003)	206	19.9%			Exp 1
Johnson & McGlone (2003)	331	24.3%			Exp 2
Echevarria et al. (2005)	#	14.8%		20.4%	indoor=open front pens
Johnson et al. (2008)	128	31.8%			
Wallenbeck & Rydhmer (2008) €	40	30.1%		23.3%	Parity 1 (outdoor) v 2 (indoor)
Wallenbeck & Rydhmer (2008) €	40	31.2%		20.5%	Parity 3 (outdoor) v 4 (indoor)

‡: total mortality reported, therefore includes stillbirths
€: organic production, 7 week weaning
#: not stated

Sow Indicators in Different Farrowing/Lactation Systems

There are a number of indicators of sow performance for the evaluation of farrowing/lactation systems. While some indicators are listed in Table 4 as examples, these are expanded in the Section 7.3.

Table 4: A selection of sow variables that could be used to evaluate different farrowing systems, with a few examples of data from the literature

Variable	Alternative system	Farrowing crate	Reference	Comments
Farrowing location outside nests	30% (Freedom farrowing system)	Not applicable	Nash (1993)	Improved with better management
	4.5% farrowings	Not applicable	Cronin et al. (2000)	
Nest-building behaviour	Started sooner and more of it	Started later and less of it	Thodberg et al. (2002a)	
• Pawing (freq)	CR (1.7) NCR (5.2)	Outdoor huts only	Johnson et al. (2007)	CR: Crushers v NCR: non-crushers
Duration of parturition	6.0 h	6.7 & 5.3 h	Svendsen & Andréasson (1980)	
	Shorter	Longer	Weber & Troxler (1988)	
	FAT2 = 121 min Trapez = 131 min	288 min	Verhovsek et al. (2007)	Crate v Trapez crate v FAT2 pen
	218 min	311 min	Oliviero et al. (2008)	42% longer in crates
	212 min	301 min	Oliviero et al. (2010)	42% longer in crates
	Indoor pens = 243 min Outdoors = 157 min	N/A	Wülbers-Mindermann et al. 2002	Primiparous sows
• Inter birth interval	19 min	30 min	Thodberg et al. (2002a)	Primiparous sows
Sow investigates neonates at birth	Possible	Not possible	Weber (1984)	In German
Manual assistance at parturition	9.1% of sows	27.5% of sows	Cronin et al. (2000)	commercial farm trial
Stillbirths	CR (8%) NCR (6.7%)	Outdoor huts only	Johnson et al (2007)	CR: Crushers v NCR: non-crushers
	1.0 per litter	0.4 per litter	Oliviero et al. (2010)	
Posture changing	47 times in first 24 h	30 times	Thodberg et al. (2002b)	56.6% higher
	N/A	Less if straw provided	Edwards & Furniss (1988)	Crates only +/- straw

Lie on side in first 24 h	Less (18.2%)	More (21.3%)	Thodberg et al. (2002b)	14.5% lower in pens
Feed intake by sow	Same	Same	Devilat et al. (1971)	To day 15
	7.9 kg / day	6.9 kg / day	Cronin et al. (2000)	
Sow backfat (mm)	14.4 mm	14.6 mm	Oliviero et al. (2010)	
Sow mortality	Group farrowing: 9.7% sow deaths	Crate: 3.5% sow deaths	Kavanagh (1995)	

Capital and Operating Costs of Farrowing Systems

Hurst et al. (1989) studied the work (time, motion and efficiency) performed by stockpeople in catching and removing litters of piglets from farrowing sheds containing different types of farrowing crates. While there were some interesting findings, such as more failed catching attempts and more time required to catch litters that had been weighed in the previous 3 days, no sow crate design variables affected any work parameter evaluated, apart from narrower piglet zones resulted in fewer steps taken by the stockpeople. Nevertheless, the authors provide a useful methodology for conducting an ergonomic evaluation of stockperson inputs associated with managing farrowing accommodation.

Weber (2000) indicated the importance of minimising piglet losses and capital expenditure in his evaluations of non-crate farrowing systems. In trials conducted over about 20 years, Weber (2000) developed and tested a number of farrowing pen systems in Switzerland in which the level of piglet mortality recorded was the same as that achieved in farrowing crates. Apart from Weber's work, very little information is available in the literature comparing the return on capital investment, labour inputs and operating costs of different farrowing/lactation systems. Some information is provided in Tables 5 and 6.

Evaluation trials by Weber over many years in Switzerland have probably contributed the most information for evaluation of different farrowing/lactation housing systems. In Australia, possibly the only information is from the Western Australian trial of Hugh Payne (reported by Loudon, 2008) which evaluated the cost of constructing Werribee Farrowing Pens in an Ecoshed was calculated. Twelve modified-design Werribee Farrowing Pens were installed and pig production was compared over a one-year period with an equivalent number of litters farrowed in conventional farrowing crates in environment-controlled sheds on the same site. The modified farrowing pens differed from the original Werribee pen design and management in a number of ways (e.g. open drain at the rear, no sloping wall panels, no piglet barrier, sows were restrained in a crate for about 12 hours around farrowing, a heated piglet creep box was provided but without thermostat control over temperature and underfloor heating). Piglet mortality was higher in the pens than crates (10.2% v 6.3% of live born). Mortality in the pens was higher in summer (15.5%), probably due to the piglet creep boxes being too hot for the piglets (the heating was not under thermostat control). In hot weather the piglets moved away from the piglet safety zones and occupied the sow zone, thus increasing the risk that piglets were crushed. The proportion of piglet deaths due to crushing in the two systems was 48% in crates and 69% in pens.

More labour was required to pressure wash the pens compared to crates between litters. This was mainly due to the concrete floor in the pen being twice the area of a farrowing crate. Other routine husbandry tasks however, took much the same length of time in both systems. The difference of 0.4

piglets weaned per litter was equivalent to one less pig per sow per year (assuming 2.4 litters per sow per year) and represented at least $50 lost income per sow per year at current prices. The 28 kg of additional feed consumed during lactation by sows in the pens incurred an additional cost of approximately $13 per sow per year (lactation diet valued at $450/t). These two items alone accounted for a difference of $63/year in gross margin per sow, equivalent to an extra cost of $2.68 per pen piglet weaned or about 3.5 c/kg HSCW (assuming 3% post-weaning mortality and 105 kg sale live weight).

Recently, Edwards et al. (2010) reported that the cost of the PigSAFE system was expected to be about 50% higher than the standard farrowing crate system due to the larger floor area required and the complexity of the pen structure. However, Edwards et al. (2010) estimated that running costs and labour requirements were expected to be similar to a crate system.

Table 5: Comparisons of capital costs for indoor farrowing/lactation systems.

Reference	Variables	Non-crate	Crate	Comments
Gravas (1982)	Piglets weaned/year	7.5% higher in pens than crates (also housed in gestation as loose or tethered/stalled)		The higher production from the pen system would compensate for extra floor space required
Weber (1997)	Capital construction cost of a module with 8 farrowing places; % of crate system	FAT1 pen =105%; FAT2 pen =107%	100%	
Weber (1997)	Area required for 1 room with 8 farrowing places	FAT1=69.1 m^2 FAT2=69.6 m^2	60.5 m^2	Pen system required ~14% to 15% more space than the crate system
Weber (2000)	Capital construction cost of a module with 8 farrowing places; % of crate system	105% to 107%	100%	
Weber (2000)	Area required for 1 room with 8 farrowing places	66.6 m^2 to 69.6 m^2	60.5 m^2	Depending on pen system, 10% to 15% more space required than the crate system
Loudon (2008)	Capital cost for modified Werribee pens in an Ecoshelter	AU $61,000 for 12 sow places		Not compared to farrowing crates
Edwards et al. (2010)	Capital cost	About 50% greater than a standard crate system; increased space and complexity of the structure		PigSAFE

Table 6: Comparisons of operating costs for indoor farrowing/lactation systems.

Reference	Variables	Non-crate (pen)	Crate	Comments
Robertson (1977)	Thermal comfort for the stockperson working in the two systems in the UK			Robertson commented that the stockperson's thermal comfort lies somewhere between the sow (13°C) and the piglets (27°C)
Gravås (1982)	Piglets weaned/year	7.5% more piglets weaned/year from farrowing pens than crates		Gravås commented that the better production from pens would compensate for extra floor space required.
Hesse (1996)	Labour time	Same in both systems	Self-cleaning slatted floors	
Weber (1997)	Annual costs; relative to crate system %	FAT1 pen = 104%; FAT2 pen = 107%	100%	Pen systems marginally more costly to operate
Weber (1997)	Daily labour (time/sow/day) Two pen types vs. crate system	FAT1=7.01 min/sow / day FAT2=6.95 min/sow / day	5.97 to 8.02 min/sow / day	On average, equivalent time required in pen and crate systems.
Cronin et al. (2000)	Occurrence of fostering (labour)	55 of 60 litters = 92%	77 of 80 litters = 99%	Similar time spent on fostering piglets between systems
Cronin et al. (2000)	Manual assistance (labour) provided at parturition	9.1% of farrowings	27.5% of farrowings	Significantly (P<0.05) more occurrence in sows in crates compared to pens
Loudon (2008)	Cleaning time	More labour (time) required due to larger floor area		Compared to work required for cleaning farrowing shed with crates on the same site.
Edwards et al. (2010)	Running costs and labour requirements	Similar to crates		PigSAFE system

7.2 Objective 2: Identify Gaps in Knowledge to Recommend how the Australian Pig Industry Could Proceed to Adopt Practical Non-Crate Farrowing/Lactation Systems

New indoor, individual farrowing pen systems for sows and litters require extra floor space and construction complexity compared to crates. Thus, greater capital investment will be required, so it is important that the number weaned is increased correspondingly to ensure that returns on investment are maintained. A possible solution to maintain economic viability if farrowing crates are removed however, involves the trade-off between a lower capital investment and lower number of piglets weaned. Further research is clearly needed on low-cost pen systems, both for systems involving individual pens as well as group pens.

The literature indicates that comparable levels of piglet survival, one of the main economic and welfare parameters for evaluating alternatives to farrowing crates, have been achieved in most non-crate farrowing systems. The lack of consistency in reporting "good" findings suggests we lack understanding of the factor(s) within the "successful" farrowing systems that contributed to their success. A key difference between farrowing sows in a confined, crate environment compared to a "loose" pen with bedding, is that the combination of space and bedding stimulate the sow's natural pre-farrowing behaviour. If we provide the sow with a stimulating (enriched) environment, then it is essential to provide the sow with an appropriate space in which to farrow, that also contains design features to promote piglet survival. Further, the sow and litter need to be managed correctly to identify problems and to rectify them as soon as possible.

The Selection and Training of Stockpeople

A major gap in knowledge concerns the selection and training of stockpeople to manage sows and litters in non-crate farrowing systems. The stockperson's level of understanding of how sows and piglets behave in the particular non-crate system, and the stockperson's ability to recognise and correct problems, seem to be essential for the success of a system. Thus, while specialist training and support information for stockpeople working with farrowing sows will be initially required, a program to identify (i.e. select) stockpeople with appropriate qualities may be needed.

If Straw Bedding is Provided at Farrowing, how Much Do We Provide?

Straw seems to provide both behavioural and nutritional benefits for the sow. These effects also appear to benefit piglets indirectly, through shorter parturition time, reduced incidence of crushing by the sow and better suckling behaviour. An important issue for Australia associated with use of straw bedding concerns the risk of contributing to heat stress on sows in summer. A gap in knowledge therefore is the optimum quantity of straw provided under Australian (summer) conditions.

What Is the Optimum Pen Size in a Non-Crate System?

The literature suggests there is a minimum size for farrowing pens (and huts). If farrowing pens are too small or too large, piglet survival seems to be adversely affected. Thus, the optimum floor area and pen dimensions need to be identified.

Can the Relationship between Farrowing Behaviour and Piglet Viability Be Enhanced?

The relationship between pre-partum nest-building behaviour and the duration of parturition is not well researched. Limited information suggests an inverse relationship, that is, as the amount of nest-building behaviour performed by the sow increases (e.g. through stimulation with nesting material), the farrowing process proceeds faster and with fewer complications. The potential benefits of faster farrowing time include reduced intra-partum stillbirths and possibly a lower incidence of unviable live born piglets. A gap in knowledge therefore concerns enhancing the purported positive relationship between farrowing behaviour and piglet viability.

Is there a Relationship between Pre-Farrowing Nest-Building Behaviour and Post-Farrowing Careful Behaviour by the Sow?

The relationship between pre-partum nest-building behaviour and the level of care taken by sows when changing posture in the days post-partum is not well researched. Limited information suggests that sows which perform more nest-building behaviour are less likely to crush piglets. A gap in knowledge therefore concerns investigating the purported relationship between pre-farrowing nest-building behaviour and reduced incidence of piglet crushing.

What Is the Optimum Piglet Weight at Birth in Farrowing Pens?

Recent information in the literature suggests that lower weight piglets are more likely to be overlain. Perhaps this is correlated to poor foetal development and is not a live weight issue per se? A gap is knowledge therefore concerns the development of the foetal pig and the interaction between viability, behaviour and survival in non-crate systems.

Managing Dunging Patterns by Sows and Piglets in Indoor Farrowing Pen Systems to Minimise Cleaning and Ensure Pen Hygiene

An important gap in knowledge is how to prevent sows and piglets from dunging in the wrong location. Farrowing pens typically have a larger solid floor area compared to crates. Understanding is lacking on how to stimulate sows to dung on the slatted floor area of pens. For piglets, a recent innovation from Denmark is the incorporation of a curved concrete join between the floor and the wall to stop piglets dunging in corners of farrowing pens.

How to Design and Manage Farrowing Pen Systems for Practical Use in Hot Climates?

Many of the farrowing pen systems reported in the literature have been designed for use in cool climates. The systems rely, at least in part, on controlling the behaviour and resting location of the sow and piglets through manipulating differentials in temperature in different parts of the pen. A very important knowledge gap for Australian conditions is how these systems will work in hot (and humid) weather. Further, if the issue is addressed by inclusion of cooling mechanisms such as fans or sprinkler systems, how will this effect piglet survival and growth? In addition, the use of straw seems to exacerbate the problem and may lead to poorer hygiene conditions for piglets.

How to Get the Piglets to Use the Safety Zones?

A major risk to piglets in the neonatal period is that they tend to remain at the sow's udder, thus risking crushing and chilling. This is despite providing a "safe", heated creep zone for the piglets. However, the biology of the pig is such that the neonates are strongly attracted to the udder. A gap in knowledge in non-crate systems is how to encourage neonates to move away from the udder to a "safer" location. Related to this is the possibility that by stimulating sows to perform more pre-farrowing nest-building behaviour, the sows become more-careful mothers.

Genetic Selection for Survival in Non-Crate Systems?

The selection for piglet survival at birth and weaning has been shown to be feasible in non-crate systems. A gap in knowledge however, concerns the welfare outcome for piglets if genetic selection for very large litter size occurs. Selection for very large litter size is occurring in Scandinavia, with a corresponding increase in litter weight. A gap in knowledge therefore, concerns how this situation will affect piglet viability, growth and survival? There will also need to be an increase in milk production from the sow to feed the larger litters.

7.3 Expanded Information on Relevant Topics in the Literature

- Nest site selection and nest-building behaviour in natural environments
- Farrowing site selection – farrowing in the 'right' location
- Prefarrowing, nest building behaviour by sows
- Space for sows and piglets
- Importance of straw bedding
- Factors associated with piglet mortality in farrowing pens
- Posture changing behaviour by sows in pens and crates
- Farrowing sows in groups indoors
- Grouping sows and piglets in "multi-suckling" lactation pens
- Outdoor farrowing
- Genetic selection
- Design criteria for indoor farrowing/lactation pen systems to minimise piglet mortality

Nest Site Selection and Nest-Building Behaviour in Natural Environments

A major emphasis of animal welfare groups wanting the use of farrowing crates banned has been to address the "behavioural needs" of the sow around the time of parturition. A number of ethological studies of the behaviour of the farrowing sow in natural environments have been reported (e.g. Stolba and Wood-Gush, 1984; Jensen, 1986).

From Jensen's (1986) study, about 2 to 2.5 days before farrowing, sows were noted to not follow the herd to their evening nests. Instead, the sows were more active and moved beyond their normal activity area. In an indoor situation, Arey et al. (1992) reported that as parturition approached, sows spent less time lying/resting together and some showed aggression towards other sows. If sows had the opportunity to achieve visual isolation from their herd mates, aggression was reduced in group farrowing situations.

In natural environments, sows showed a strong tendency to select a nest site outside their normal home range (Jensen, 1986). Nest sites tended to be located in a "grove", characterised by a combination of protection and overview of the surroundings. Nests also tended to be situated under the protection of horizontal branches. In summer compared to winter, nest sites was less protected from above and less nesting material was collected. Jensen suggested that nesting behaviour was, to some extent, feed-back regulated. Experience also seemed important as gilts used less nesting material compared to sows. Piglet mortality during the first 3 days of lactation in the farrowing nests was 20.7% (Jensen, 1986).

In the USA, a study by Dellmeier and Friend (1986) reported observations on a group of 13 sows (18 farrowings) in a 0.55 ha paddock of unmaintained pasture containing brush, trees, a wallow, a concrete feeding platform and multiple (more than 13) A-frame shelters. Only one-third of sows farrowed in the artificial shelters. Sows farrowing in other locations chose sites with at least one vertical feature and close to water.

In a later controlled study, Jensen (1993) compared the pre-farrowing behaviour of sows indoors in pens either containing enrichment from a soil bed and straw in a rack or no enrichment (bare pen). The pens measured 2.5 x 3 m. Analysis of the data for sows in the enriched environments suggested two clusters of behaviour: a 'preparation factor' (standing, nosing and rooting) and a 'nest material factor' (walking, carrying material and arranging). Jensen's findings support a model in which external stimuli (hormones) control the first part of the activity, associated with preparation of the nest site, while control over the second phase, gathering and arranging, are largely dependent on external stimuli.

More recently, Algers & Uvnäs-Moberg (2007) published a review of maternal behaviour in pigs indicating that the onset of nest-building behaviour in sows is triggered by a rise in prolactin concentrations, which is itself related to decreased progesterone and increased prostaglandin concentrations. Some nest-building activities such as carrying and depositing straw seem to be related to changes in somatostatin and progesterone concentrations. Nest building ends when oxytocin concentrations begin to rise.

Farrowing Site Selection – Farrowing in the 'Right' Location

A very important principle of non-crate farrowing systems is that the sow chooses the appropriate location as her farrowing nest site. This is regardless of whether the sow farrows indoors or outdoors. During the development of the Freedom Farrowing System, Baxter (1991) reported 12% piglet mortality (from 40 litters). Subsequently, a six-sow place version of the system was installed. Nash (1993) evaluated the first 6 batches (n=34 sows). In Batch 1 only one of five sows chose to farrow in a nest. Batch 2 was slightly better (2 of 5 sows). At that point, a stockperson who had worked with the farrowing system during its development phase was brought in to provide advice. The use of the prescribed farrowing sites increased to 79% for the next four batches of sows. Nevertheless, piglet mortality remained higher than acceptable, averaging 25% over the six batches. Overlying by the sow was the main cause of death (55% of deaths). The mortality figure is probably an under-estimate. In 5 of the 6 batches, some piglets were removed from the system by fostering. Indeed, in one batch all pigs were removed on day 4 presumably to avoid further piglet deaths. Another important finding from Nash's (1993) research was that some sows could be very 'destructive' before farrowing. Nash (1993) commented that in subsequent batches of sows, a number of sows had to be removed from the system and placed in a crate before "*they demolished the system*". A third point of interest is the comment of Nash (1993) that if sows appeared to have chosen not to farrow in one of the nest sites provided, then the stockperson could move the sow into an unused nest and lock her in overnight. This could have also interfered with the process of farrowing, as discussed by Lawrence et al. (1992).

In the group farrowing pen systems developed by Baxter (1991) and van Putten and van de Burgwal (1990) respectively, two major problems were that a proportion of sows either did not use the prescribed nest site (Baxter, 1991), or two sows occupied the same farrowing cubicle (van Putten and van de Burgwal, 1990). In each case, the prescribed nest site was designed to include piglet survival features such as heated safety zones, hence the desire for sows to farrow in the 'right' place.

While one important principle of nest site selection by sows in semi-natural conditions is that they isolate themselves before farrowing (Jensen, 1986), another is that nests provide appropriate thermal protection for the newborn pigs. Algers and Jensen (1990) measured temperatures within farrowing nests in winter, recorded within 5 cm of piglets, and found temperatures within the nest were mostly unaffected by external air temperature. Nest temperatures varied between 11 and 26°C (ave 20.3°C) while outside temperatures ranged from -17 to +7°C (ave -1.5°C). While Algers and Jensen (1990) concluded on the importance of providing plenty of straw for sows in cold conditions, Li et al. (2010) reported that straw bedding in a group farrowing pen system in the USA in summer imposed problems associated with heat stress for sows, which caused resultant problems for piglet survival and growth.

In warmer conditions then, Cronin and van Amerongen (1991) investigated the effect of providing a "completed" farrowing nest for sows in farrowing crates (small amount of straw bedding plus a hessian cover over the sow , which was removed about 6 h after farrowing) on nesting behaviour and response to piglet distress cries, and piglet mortality. In the control treatment, sows farrowed in identical crates but without straw bedding or a hessian cover. About 6 h after farrowing, the sows received straw bedding. In the enriched treatment, sows performed more prefarrowing behaviour and they were more responsive to the vocalizations of their piglets. No piglets died (from 8 litters) in the enriched treatment, compared to 10.6% of live born in the control (crate without straw bedding or hessian cover).

A series of experiments was conducted by Haskell et al. (1994) to use sow behaviour to indicate preference for farrowing site. Individual pre-parturient sows were introduced into a 6.5 x 7 m test arena (45.5 m^2) with a 2 x 2 m pen in one corner. No straw was provided on the concrete floor. In a comparison of gilts versus sows, all sows farrowed in the smaller pen, while half of the gilts chose to farrow in the smaller pen. In subsequent experiments, all sows farrowed close to a wall with their back against the wall.

In a later preference experiment by Cronin et al. (1997), primiparous sows were provided with two farrowing nests in a long pen. The objective of the experiment was to investigate sow preference for a farrowing (nest) site relative to the (human) activity area in the pig shed. Within each pen, one nest was located near to, compared to far away from, the activity area. Four combinations of nest entrance orientation were also compared: 1) all entrances faced the activity area, 2) the closer nest faced the activity area and the further nest faced away from the activity area, 3) the closer nest faced away from the activity area and the further nest faced towards the activity area, and 4) all entrances faced away from the activity area. A total of 32 sows were tested, and the experiment indicated that primiparous sows preferred a nest entrance oriented towards the shed activity area. There was no apparent preference for distance away from the shed activity area and nest site selected for farrowing. In the treatment in which both nests faced away from the human activity area, 3 of the 8 sows farrowed all their piglets outside the nests provided, while another sow farrowed her litter in multiple sites.

Recently, Pedersen et al. (2007) used sow behaviour to identify preference for floor temperature of sows at parturition. Intuitively, one would expect sows to be attracted to a floor temperature similar to that required by new born pigs. In Pedersen's experiment, sows were placed into farrowing pens 7 days before due farrowing date. The pens had 2 floor types – a solid concrete floor area and a slatted concrete floor area. For half the pens the solid area was heated with inbuilt electric heating to provide a surface temperature of 34°C. Average room temp was 19.8°C. Sows had no preference for lying location.

Prefarrowing, Nest Building Behaviour by Sows

One of the earliest papers that investigated pre-farrowing behaviour measured the incidence of 'major' posture changes (Hansen and Curtis, 1981). These authors conducted a small factorial experiment comparing accommodation type (crate versus very small pen) and bedding (straw versus no straw). Sows in crates compared to pens showed a higher the incidence of major postural changes in the 48 h pre-farrowing. However, Baxter's (1982) paper on nesting behaviour of sows in confinement was possibly the earliest work providing detailed descriptions of nest-building behaviour in sows in confined conditions. The research reported by Baxter (1982) was a pilot study for a larger project on the design of alternative farrowing systems, which stimulated subsequent research by a number of scientists (e.g. Schouten, 1986; Arey et al., 1991, amongst others).

For example, Arey et al. (1991) studied the nest-building behaviour of pre-partum sows individually in pens measuring 5.0 x 2.5 m. Each pen consisted of two areas with different floor surfaces – sand or concrete. The sand was 60 cm deep and was at the same level as the concrete floor. Food, water and a straw dispenser were located at the join between the two floor-type areas, and nest-building behaviour was defined as rooting, pawing and carrying straw. The first six sows were allowed to perform their own nest-building behaviour and to construct their own farrowing nest. The researchers measured the dimensions of the nests and the amount of straw used for the nest. For the second six sows, on day 113 of gestation, a nest was constructed for the sows based on the median dimensions and mass of straw used by the first 6 sows. The median nest size was 1.62 x 1.07 x 0.21 m deep, and 23 kg of straw was used. For the sows that were provided with a constructed nest, they all used the nest provided and took 9.5 kg (median) from the straw dispenser. From this research, Arey et al. (1991) suggested that nest building comprise three stages; commencing with excavation of a hollow, then collection of nest material and manipulation of the material in the hollow to form a nest.

A number of studies followed in which the function of feed-back from nest-building was investigated. Herskin et al. (1998) conducted a factorial experiment stimulating prepartum sows through the provision of floor type (sand versus concrete) and bedding (straw versus no straw). Sows that performed less risky behaviours such as posture changing and rolling, crushed fewer piglets. Sows that farrowed in the concrete floor pen without straw crushed more piglets than sows in pens with sand, straw or both. To investigate whether feed-back from a farrowing nest affected sow behaviour (activity) and response to piglet stimuli, Pedersen et al. (2003) allowed sows to build a farrowing nest in Schmidt pens. At 8-10 h after the onset of nest-building, and every 4 h until farrowing began, the nest material was removed for half the sows. Sow behaviour and heart rate were monitored. In the treatment group in which the constructed nest was removed, the level of maternal responsiveness (to piglet stimuli) was higher.

Damm et al. (2003) placed primiparous sows individually in farrowing pens with a nesting area comprising a peat floor and nesting materials such as straw and branches. Additional straw and branches were provided regularly from day 114 of gestation, and sows had unlimited access to the material. In the experimental treatment, 10-12 h after the onset of nest building and again at every 4 h until birth of the first piglet, the nest was removed. In the control treatment, nests were not removed. Sow behaviour, heart rate and blood cortisol and oxytocin were measured. Treatment did not affect nest-building behaviour. Some gilts also performed nest-building during and after parturition, but this was not related to the treatment of removing the nests. Removal of nests resulted in elevated heart rate before parturition compared to the control treatment. This may have been due to increased activity by the sow or the presence of the human removing the nest? However, heart rate in the control treatment was consistently higher than in the nest-removal treatment. Cortisol concentrations were elevated in the nest-removal treatment compared to the control treatment, and the slope of increase was steepest in the last hour prepartum. Oxytocin was not affected by treatment.

There have been some recent reviews of maternal behaviour in pigs. Algers and Uvnäs-Moberg (2007) indicate that the onset of nest-building behaviour in sows is triggered by a rise in prolactin concentrations, which is itself related to decreased progesterone and increased prostaglandin concentrations. Some nest-building activities such as carrying and depositing straw seem to be related to changes in somatostatin and progesterone concentrations. Nest building ends when oxytocin concentrations begin to rise. Wischner et al. (2009) reviewed the literature on prefarrowing nest-building behaviour by sows and concluded that sows are highly motivated to perform nest-building activities prior to parturition. According to Algers (1994), the performance of at least some aspects of the behaviour leads to better health and welfare of both the sow and the piglets. This conclusion has been supported by other studies that show a positive association between pre-farrowing nest-building behaviour and piglet survival. In relation to the assumption that nest-building behaviour is important for sow welfare and reproduction (e.g. via piglet survival), Wischner et al. (2009) considered that the provision of space for the sow and nest-building material (straw) are therefore prerequisites of a loose-housing system for the farrowing/lactating sow.

Space is important for sow movement, but how much space is required to satisfy sow motivation for pre-farrowing locomotion? To answer this question it will be necessary first to determine what motivates sows to locomote? Is the sow trying to find isolation, looking for a suitable farrowing site, looking for bedding, or something else (e.g. Arey et al., 1991)? Studies have looked at these issues. Alternately, is space only required for nest-building within the farrowing site? If so, what area is required?

Wischner et al. (2009) concluded that the following actions should be implemented:

- Sow management goals: assuming that the use of farrowing crates might not be allowed in the future, suitable nesting material and space for nest-building-performance should be provided in the pre-partal period.
- Research objectives: alternative pens and nest-building material should be tested with regard to practicability, application and effects on sows and piglets. Individual characteristics of single sows like maternal behaviour should be examined with respect to their genetic determination in order to breed sows better adapted to more open farrowing surroundings.
- Legislation: results from research should be implemented into consistent EU-Regulations, considering space and material requirements in enriched environments.

Space for Sows and Piglets

Farrowing crates are criticised for prohibiting the ability of sows to turn around (e.g. to perform nest-building behaviour), and a small number of experiments have been published investigating turning around by sows in modified farrowing crates. Heckt et al. (1988) compared the prepartum behaviour of gilts in a conventional farrowing crate, a turn-around crate and an open pen. As expected, the gilts were unable to turn around in the farrowing crate, but turned through 90 degrees twice as often in the turn around crate compared to the open pen. The open pen treatment measured 2.1 m x 1.5 m. One innovative farrowing crate designed to enable the sow to turn around was the 'Ottawa' farrowing crate (Fraser et al., 1988). The crate width was 0.75 m at the bottom (between opposing inward-positioned prongs) and 1.15 m at the top, enabling the sow to "turn around with little apparent difficulty". No difference in stillbirth rate was found between the Ottawa crate and conventional crates (Fraser et al., 1997). The results reinforce the point that there is likely to be a minimum space (and dimensions) required for sows in the pre-farrowing period for the increased pre-parturient activity to benefit piglet survival, including reduction in stillbirths. One alternative is to keep the sow in a crate for the first few days of lactation, then "open" the crate to provide more space for the sow, including space to turn around or space to avoid the piglets. Cronin et al. (1991) found that towards the end of the fourth week of lactation, primiparous sows in both farrowing crates and pens showed evidence of elevated stress response, probably from not being able to avoid their piglets. Devilliers and Farmer (2008) compared sow behaviour on days 4 and 18 of lactation in conventional farrowing crates, and the same design crates that could be opened at the rear to allow the sow access to an additional 2.4 m^2. Sows in this treatment were given access to the additional space from day 4 of lactation. Sows utilised the extra space by spending more than 85% of the time there, including 70% of suckling bouts.

While limiting space could interfere with pre-farrowing activity of sows, providing too much space by increasing farrowing pen size could adversely affect newborn pig survival. Cronin and Smith (1992a) and Cronin et al. (1994) concluded that piglet mortality was higher in open pens than crates due to the extra space available to litters in the pens. Factors associated with the extra space that may contribute to piglet mortality include lower ambient temperature and draughts which increase the risk of chilling and thus starvation and overlying (e.g. English and Morrison, 1984). Recently, Oostindjer et al. (2010) reported an experiment in which sows and litters were housed in 'barren' or 'enriched' environments from day 4 of lactation. The barren environment occupied 9.2 m^2 and did not contain bedding material, whereas the enriched environment occupied 18.4 m^2 had was supplied with various substrates to stimulate investigation by the piglets. However, prior to day 4, the sows were housed in farrowing crates situated within the large pens. Piglet mortality over the first 3 days was 19.3% and 23.4% in the 9.2 m^2 and 18.4 m^2 pens, respectively (unpublished data provided by Marije Oostindjer, 20 November 2010).

Changing the dimensions of the nest area in the Werribee Farrowing Pen was investigated by Cronin et al. (1998) in an experiment involving primiparous sows. The experiment had a 2x2 factorial design and compared the main effects of nest area orientation (wide v narrow) and space (large v small). The small nest area treatment adversely affected pre-farrowing (nesting) behaviour, resulting more posture changes by sows and poorer suckling behaviour, compared to the other treatments. Piglet mortality was 7.3% in full-sized nests and 13.3% in reduced-size nests. A subsequent experiment by Cronin (1997) found that piglet mortality was higher in farrowing pens than crates. Most of the sows included in this experiment were multiparous, and it was thought that the farrowing nest dimensions (1.8 m) were too narrow for multiparous sows.

Importance of Straw Bedding

The importance of bedding material for parturient sows has long been recognised (e.g. Harris, 1906). However, with the move to intensive farrowing crates with perforated floors resulted in reduced use of straw to avoid blocking of underfloor drainage systems. Recently, there has been increased interest in the importance of straw bedding for sows around parturition. In the older literature, there are some reports indicating the potential benefits of straw for piglet survival. For example, Metz and Oosterlee (1980) reported an experiment in which they compared the antibody response of sows to a challenge with sheep red blood cells (SRBC), and the behaviour of sows and their litters. The sows were farrowed in either straw-bedded pens or conventional farrowing crates (without straw). Not surprisingly, there were many differences in pig behaviour between the two environments due to the two levels of restraint and access to bedding in the pen treatment. Piglets in the straw bedded pens spent more time lying close to the sow in early lactation than piglets in crates (e.g. day 2 of lactation 60% versus 8% of observations, respectively). Loose housed sows investigated (touched, sniffed) their piglets about four times more often than sows in farrowing crates. However, piglets investigated their dam equally in pens or crates, and there was no difference in the occurrence of piglet-to-piglet contact, although piglets in straw-bedded pens spent more time in "play" behaviour than piglets in crates.

Two interesting findings related to piglet survival were that: (1) antibody titres were higher in sows in straw-bedded pens compared to crates from day 10 to 27 of lactation, although the difference was not statistically significant, and (2) titres were higher in piglets from 24 hours till 14 days of age in straw-bedded pens compared to farrowing crates, indicating that more antibodies were absorbed from the colostrum of sows in straw-bedded pens.

The influence of straw on sow behaviour and piglet survival around parturition has been investigated in a number of studies. Vellenga et al. (1983) compared the effects of straw versus no straw in the farrowing crate on mortality, morbidity and injuries of piglets in 375 litters. The provision of straw reduced stillbirths (5.90% v 8.05%), preweaning deaths (11.97% v 15.44%), morbidity (33% v 44% of piglets) and injuries amongst piglets compared to litters born in crates without straw bedding. In a small experiment by Edwards and Furniss (1988) with 10 sows per treatment, farrowing behaviour of sows and piglet survival in crates with and without chopped straw were compared. The addition of straw resulted in fewer major postural changes by sows early in parturition (e.g. first 4 piglets born), a lower proportion of stillbirths (5.8% v 7.9%) but no difference in preweaning deaths (12.3% v 12.1%). Cronin & van Amerongen (1991) performed a similar experiment and reported reduced piglet mortality in the straw-added treatment in farrowing crates. The provision of straw for sows was also found to positively modify suckling behaviour, a finding that was subsequently reported in other experiments (Cronin and Smith, 1992a & b; Cronin et al., 1994), and Schouten (1991) describing his PhD research (Schouten, 1986) indicated that suckling behaviour did not establish as easily in the crate- than straw pen-reared gilts.

Factors Associated with Piglet Mortality in Farrowing Pens

There have been many investigations to identify why more piglets tend to die in farrowing pens than farrowing crates, and especially why crushing by the sow is typically higher when sows are "loose". Wechsler and Hegglin (1997) video recorded 11 sows at and after farrowing to quantify the performance of "risky" behaviours by the sow and her response to her piglets. A number of "risky" behaviours/events were categorized by the authors, for example descent from standing to lying and rolling from lateral to sternal recumbency. The distress calls of one piglet from each litter were recorded and re-played to the sow on 3 occasions (from day 4 of lactation) after she had just finished the first lying down pattern at the nest site after feeding time. In 14.6% of lying down events and 24.6% of rolling events, there was at least one piglet 'in danger'. Lying down by sows mostly occurred vertically (93%) and 'flopping' down occurred less (7%). Sows were individually characteristic in how they performed these movements, for example, with some sows never 'flopping' down. Sows that performed "better quality" posture changing behaviour, and that were more responsive to the distress calls of piglets after posture changing, were less likely to crush piglets (as the primary cause of death).

Weary et al. (1998) investigated the relationships between litter and pen features, and sow behaviour associated with crushing piglets. The experiment involved use of a farrowing pen with either plastic-coated perforated metal floor or a solid concrete floor. For half the farrowings, a metal anti-roll bar bisected the pen. No bedding material was provided for the sows. Positioning the anti-roll bar down the middle of the pen seemed to increase proportion of deaths due to crushing (7.0% v 7.6%). Piglets crushed on day 1 of life tended to have lower birth weight. Mean birth weight of piglets that survived was 1.35 kg. Mean birth weight of piglets that were crushed on day 1 was 1.03 kg or days 1-3 was 1.16 kg.

Andersen et al. (2005) compared the performance of 59 sows that farrowed in loose pens (3.3 m x 1.8 m; plus 2 kg straw provided the day before parturition was due), to identify sows that crushed piglets during the neonatal period. The video records of these sows were studied. There were 11 litters in which two or more piglets were crushed. Crushing accounted for 35% of pre-weaning mortality (35 piglets were crushed) and only 3 (9%) of crushed piglets had not received milk. Sows that crushed multiple piglets had larger litters (15.4 v 12.6), and most incidents of crushing occurred as a result of the sow rolling over from the belly to the side. Sows that were identified as non-crushers performed significantly more pre-farrowing nest building activity in the period 6-8 hours pre-partum than sows that crushed multiple piglets. In the last hour before parturition, sows that crushed multiple piglets performed more nest building, suggesting that they were less prepared for parturition and had not completed their nesting behaviour. Sows that were 'non-crushers' responded sooner to the distress calls of piglets than 'crushers'.

Design mechanisms in farrowing accommodation to separate young piglets from the sow when she is active (standing) is not new. Berg et al. (2006) examined the effects of closing the piglets in the creep area while the sow was fed, for the first 2 or 4 sow feeding events. A non-enclosed treatment was also included. There was no effect of the husbandry procedure on piglet mortality, which ranged from 15.8% to 17.4% of live born. The proportion of piglets lying in the creep area increased over the first 3 days of lactation, which corresponded to a lower proportion of piglets lying close to the sow. Another mechanism to manipulate where piglets rest is the heater. Heat may either be provided from above the piglet, e.g. from a heat lamp, or from below e.g. from a heat mat on the creep floor, or from an electric heating element within the floor or a piped-hot-water system.

In an experiment by Malmkvist et al. (2006), sows were farrowed in pens and half were exposed to under floor heating (water based system). Heating to the floor was commenced after the onset of nest building until 48 h after the birth of the first piglet. The control sows had no floor heating. Surface floor temperatures were 33°C for the heat treatment and 21°C for the no-heat control. Piglet mortality was significantly lower in pens with heat floors (mortality to day 7 was 8.7% v 15.5% for heat v no heat, respectively). Thus, floor heating (around 33°C) during the first 48 h after parturition contributed to improved piglet survival. The authors also reported shorter latency to first suckle and earlier recovery of piglet body temperature, for floor-heated litters compared to control litters which did not receive the additional floor heating.

To identify the main factors associated with piglet mortality in loose farrowing pens, an on-farm survey was conducted by Andersen et al. (2007) involving 39 Norwegian sow herds. The herds were selected at random for inclusion in the study. Preweaning mortality ranged from 5-24%, with the majority of herds in the 14-16% range. Piglet mortality was lower in herds that:

- fed hay to the sows in gestation (tendency)
- provided more (rather than less) litter on the floor of the nest area
- ensured neonates received colostrum
- used rails along the walls of the farrowing pen

Similarly, Weber et al. (2009) conducted a statistical analysis of individual litter records for 2002/03, of farms participating in the UFA2000 Swiss sow recording scheme and using loose farrowing pens (44,278 litters on 240 farms). After omitting data from certain farms (e.g. farms with multiple types of farrowing pen, small farms, farms that had supplied doubtful data, etc), data for 99 farms and a total of 12,155 litters from 7,323 different sows were analysed. Average piglet mortality was 11.8% of live born and crushing accounted for 47% of deaths. The findings of the survey analysis are summarised in Table 7, and indicate that parity of the sow had a strong effect on total mortality and crushing. After adjusting for parity, there was a highly significant relationship between the number born alive in the litter and losses. The availability of piglet protection bars only had a weak association with piglet mortality. Season had a significant impact on overall piglet mortality and losses due to crushing. Compared to the cold months, fewer piglets were crushed in the transition period between cold and hot seasons (effect = -0.09 per litter), but more were crushed in the hot season (effect = +0.02 per litter).

Table 7: Variables analysed by Weber et al. (2009) in relation to piglet losses due to all causes and due to crushing

	Total mortality	Crushed	Other causes
Covariates			
Herd size	no effect	no effect	no effect
Pen size	trend (P=0.087)	trend (P=0.067)	no effect
Born Alive	P<0.001	P<0.001	P<0.001
Factors			
Parity	P<0.001	P<0.001	P<0.001
Possibility of confinement	no effect	no effect	no effect
Piglet protection bar	trend (P=0.09)	no effect	trend (P=0.084)
Season	P=0.048	P=0.023	P=0.61

Posture Changing Behaviour by Sows in Pens and Crates

One of the main causes of death amongst newborn piglets is crushing by the sow (Damm et al., 2005). The two most common methods by which sows crush piglets are (1) during posture changing, and especially when the sow descends from standing to lying posture, and (2) during rolling (over) while in a recumbent (lying) posture, for example, from lying on the belly to the side, or from one side to the other side via the belly. Not surprisingly, a very large number of experiments have been reported studying the sow behaviour during posture changing, and the factors affecting how the sow changes posture including the presence of piglets, etc.

Crushing of piglets is a major cause of mortality, and was found to be related positively to lateral lying during the 4 h before the birth of the first piglet (Pedersen et al., 2006). Weary et al. (1995) studied 20 sows that were housed in two farrowing systems, crates and pens. The farrowing and early lactation periods were video recorded to quantify posture changing by the sow, including rolling movements. Rolling movements resulted in 10 piglets crushed in pens but none in the crates. In the crate, 3 piglets were crushed when the sows transitioned between lying and sitting posture.

When sows descended from standing to lying posture, Cronin et al. (1996) observed that sows pressed against the wall of the farrowing pen or farrowing crate bars on 96% of occasions. However, sows in farrowing crates were less likely to nose or paw at the floor prior to descending from standing to lying than sows in farrowing pens (27% v 65% of occasions, respectively). Similarly, after completing the descent, sows in crates were less likely to grunt (30% v 72% of occasions).

Marchant et al. (2001) studied posture changing behaviour of sows in relation to the risk of crushing / near-crushing of piglets during the first 7 days of lactation, in ("loose") farrowing pens. The observations were recorded in a community (group) farrowing system containing 5 pens. Pens measured 1.52 m wide x 2.75 m long. Two pens had 2 sloping walls and 3 pens had perimeter piglet-saver rails. Stillbirths were recorded at 10.7% of total born and piglet deaths to day 7 were 25% of born alive. Live born mortality in individual litters ranged from zero to 53.8%. Almost three-quarters of piglet deaths occurred as a result of traumatic injury. Of the 50 piglet deaths, 6 were not associated with any posture change but were the result of being 'trodden-on by sow'. The remaining 44 deaths were associated with eight of the 11 posture change types recognised by Marchant et al.

(2001). Descending movements of sows resulted in the majority of piglet deaths: 55% with the stand to lie movement and 9% with the sit to lie movement. The remaining 34% of deaths were associated with the sow rolling in the pen; 20% of deaths were associated with the sow changing posture/position commencing the movement whilst lying on the sternum and 14% occurred when the movement commenced when the sow was lying laterally. Postural descent movements were most dangerous if the sow performed the movement in the "open", that is away from the walls or panels.

Care taken by sows to avoid crushing piglets when changing posture was investigated by Valros et al. (2003). Four 'careful behaviours' were classified: rooting or sniffing piglet prior to lying down, careful standing-to-lying and no piglets in the danger zone at standing to lying. The occurrence of these behaviours was studied at intervals during lactation, and posture changing care was analysed in relation to suckling, sow body resource mobilisation and litter mortality. Activity level of the sow and care in posture changing were highly repeatable within-sow. There were no associations with nursing behaviour or growth of the piglets. Sows with low mortality were more active on day 3 of lactation. Sows with no crushed piglets showed a higher incidence of rooting the floor on day 3 than sows with at least 1 crushed piglet. Opportunity to either select careful sows based on pre-lying behaviour, or stimulate pre-lying rooting of the floor/bedding behaviour.

Damm et al. (2006) tested sows in late gestation (rather than post-farrowing) to test preference for lying down against different types of wall surface. In experiment 1 a solid sloping panel, a outward curved sloping panel or a rail wall of horizontal wooden dowels, were provided to sows. On 80% of occasions sows lay down against a panel (wall) rather than in the open away from a wall. Sows had a strong preference for the wall at the back of the pen over the side walls. In experiment 2, a solid vertical wall, a solid sloping wall or horizontal piglet rail were compared. The overall finding that sows lay against a wall on 86% of occasions and 14% of occasions in the open, support the earlier report of Cronin et al. (1996). There were significant effects of position and wall type on lying preference. Sows least preferred option was the horizontal rail. There was no difference between the preference for vertical and sloping solid walls.

Like Marchant et al. (2001), Burri et al. (2009) focussed on piglets in potentially dangerous situations involving the sow changing posture, in which piglet crushing may occur. The researchers compared behavioural differences due to the provision of long straw versus short-cut straw at farrowing. After farrowing, all sows received short-cut straw. While straw length had a minimal effect on pre-farrowing behaviour of sows, the number of dangerous situations for piglets was positively associated with the occurrence of nest-building during farrowing.

A large number of sows were video recorded from 12 h pre-partum to 48 h post-partum in farrowing crates without bedding, over one year by Wischner et al. (2009b). Twenty sows that crushed one or more piglets (C-sows) were compared to 20 sows that did not crush any piglets (NC-sows). Analysis of the sows' postural behaviour traits was analysed. Before parturition, the NC-sows were more restless, stood more frequently and performed more nest-building behaviour. After parturition, there were no differences in the types of behaviour C-sows and NC-sows performed. However, C-sows showed more rolling movements and they preferred ventral recumbency within the rolling movements and as the final position of descending from standing to lying. Bouts of sitting were longer for C-sows than NC-sows. NC-sows performed lateral recumbency much longer and also more often as the final position of descending from standing to lying. The results suggest that sows that crush piglets in the neonatal period differ from those that do not crush piglets, and that pre-partum nest-building behaviour is important to minimise piglet crushing.

One suspected cause of crushing in sows fearful of humans is that sows become less careful in the presence of the stockperson. Lensink et al. (2009) attempted to investigate this issue but reported no significant correlation between the number of postural changes by sows after farrowing and crushing of piglets.

Recently, Wischner et al. (2010) reported a further analysis of the data they previously reported in Wischner et al. (2009b), with a focus on the different elements of sow behaviour performed around the time of posture changing. Sows that did not crush piglets, particularly primiparous animals, were more likely to perform sniffing as an element of pre-lying behaviour, and for longer duration than sows that crushed piglets. Non-crushing sows, in particular multiparous sows, looked around more than crushing-sows. Nosing, often performed in association with looking behaviour, was also more common by non-crushers than crushers. The duration of piglets sleeping and active at the udder tended to be longer for crushers than non-crushers.

Farrowing Sows in Groups Indoors

The management of sows in groups indoors is seen as problematic. Nevertheless, a number of indoor group farrowing systems have been trialled. Amongst the earliest researchers who investigated key behavioural features for sows in the farrowing environment were Stolba and Wood-Gush (1984). Fundamental research commenced in 1978 at the Edinburgh School of Agriculture on domestic Large White pigs released into "the Edinburgh Pig Park". The behaviour of the pigs was studied in detail over many years, through reproductive cycles, to investigate the unrestricted behaviour of pigs. One outcome of this research programme was the development of the 'family pen system' for pigs. The system maintained sows in groups of four and their piglets remained with the group until 17 weeks of age. Arey and Sancha (1996) compared sow and piglet behaviour and piglet survival and growth in the 'family pen system' to conventional farrowing crates. Sow and piglet behaviours were different between the two environments. Key differences were that sows were recorded lying inactive less in the pens than crates and there was more nursing behaviour by sows in the pen system. Time spent suckling was longer in pens than crates and the proportion of "successful" suckling bouts in which milk let-down occurred was higher in pens than crates. Although stillbirths were less common in pens than crates (5.4% v 12.3% of total born), piglet mortality was high in both systems (deaths to 4 weeks of age were 28.5% and 25.2%).

A very important principle of non-crate farrowing systems is that the sow chooses the appropriate location as her farrowing nest site. During the development of the Freedom Farrowing System, Baxter (1991) reported 12% piglet mortality (from 40 litters). Subsequently, a six-sow place version of the system was installed. Nash (1993) evaluated the first 6 batches (n=34 sows): in Batch 1, only one of five sows chose to farrow in a nest., and in Batch 2, two of 5 sows farrowed in a nest. The researchers then sought the advice of a stockperson who had worked with the farrowing system during its development phase. By following the stockperson's advice, the use of the prescribed farrowing sites increased to 79% for the next four batches of sows. Nevertheless, piglet mortality remained higher than acceptable, averaging 25% over the six batches. Overlying by the sow was the main cause of death (55% of deaths). The mortality figure is probably an under-estimate, for in 5 of the 6 batches, some piglets were removed from the system by fostering. Indeed, in one batch all pigs were removed on day 4 presumably to avoid further piglet deaths.

Another important learning from this research was that some sows could be very 'destructive' before farrowing. Nash (1993) commented that in subsequent batches of sows, a number of sows had to be removed from the system and placed in a crate before "they demolished the system". A third point of interest is the comment of Nash (1993) that if sows appeared to have chosen not to farrow in one of the nest sites provided, then the stockperson could move the sow into an unused nest and lock her in overnight. This could have also interfered with the process of farrowing, as discussed by Lawrence et al. (1992).

Other group farrowing systems were also developed around the same time. Two Dutch systems were developed which were labelled "integrated" (Buré and Houwers, 1990) or "multi-phase" systems (van Putten and van de Burgwal, 1990), respectively. In both systems the sows remained in groups throughout gestation and farrowing/lactation. Sows wore transponder collars which gave them access to feed from an electronic feeding station, and in the "integrated" system, access to different compartments in the pig shed. In the group farrowing pen systems developed by Baxter (1991), van Putten and van de Burgwal (1990) and Buré and Houwers (1990), two major problems were that a proportion of sows either did not use the prescribed nest site or two sows occupied the same farrowing cubicle. In each pen system, the farrowing nest sites were designed to include piglet survival features such as heated safety zones, hence the desire for sows to farrow in the 'right' place.

In Norway, Bøe (1994) visited 15 pig farms where sows were housed in "integrated, loose housing systems" utilising electronic sow feeding technology, to investigate maternal behaviour by the sows and piglet production. Bøe commented: "*As many of the stockpersons were still unfamiliar with the system, the routines of management varied considerably. The sow was normally locked in the farrowing pen for 2-3 days after farrowing, but in some herds this period was extended to at least one week.*" The average piglet mortality across the 15 farms was 16.3%, worse than the national herd average for Norwegian farms of 14.4%. An issue identified by Bøe (1994) was that a small proportion of sows "intruded" in the farrowing pens of other sows. However, these occurrences tended to occur later in lactation, since many farmers kept sows locked in their farrowing pens through early lactation.

In a trial conducted by Kavanagh (1995) in Ireland on a "high welfare, 500-sow unit", piglet mortality was compared under two farrowing systems in different time periods. Initially, sows were housed in an integrated, group system and fed using and electronic sow feeders. For farrowing, sows were provided with "free-access farrowing nests" in a straw yard. After 18 months, the "free-access farrowing nest" system was considered a failure and was replaced with a farrowing crate system. Sows were then individually fed. Piglet mortality data from each system, from two, 6-month production periods, were compared by Kavanagh (1995). The farrowing data of more than 500 sows were included in each time period. Piglet mortality in the group system was 19.2% of born alive (54% of deaths were due to overlying by the sow) and 6.0% (33.6% due to overlying) in the crate system. Sow mortality in the group farrowing system declined from 9.7% to 3.5 percents following replacement of the nests by crates. As well as measuring the incidence and causes of piglet mortality, Kavanagh (1995) applied the UK Farm Animal Welfare Council's Five Freedoms Concept for good welfare to assess sow and piglet welfare in the two systems. The group farrowing pen system was considered to fail a minimum of two categories, and possibly four, of the Five Freedoms categories for the sow and 4 of the categories for the piglets. In comparison, the crate system was considered to have failed in one category for the sow (#4 – normal behaviour) and none of the categories for piglet welfare.

Honeyman (1995) and Halverson et al. (1997) described a Swedish system for managing sows in groups in a straw-based, loose farrowing system (Västgötmodellen) around farrowing and during lactation. Piglet mortality in two versions of the Västgötmodellen system were reported at 14.5% of live born. However, the majority of farms farrowed sows in individual pens with straw bedding (Ljungström system), with the sows and litters being grouped in a lactation pen between 14-20 days of lactation. A smaller number of farmers used the Thoestensson system, in which sows were farrowed in groups. The authors of the report indicated that both systems "*work best for farmers who are proactive managers, pay close attention to details, enjoy working with pigs...*". Piglet mortality records for other herds in the Scan-Farmek database was 15.5% of live born. These systems have also been adopted by pig producers in the United States. Two farmers, Jungclaus and Jungclaus (1997), reported their experience of adopting the Swedish-style group farrowing pen system in the USA. Piglet mortality was high (31.4%) compared to the regional average for farms using conventional farrowing crates (11.2% losses). However, the authors made some relevant anecdotal comments such as: "the sows that showed the most elaborate nesting behaviours were also the best milkers and mothers. These behaviours were noted for culling purposes"; and "it became clear that some sows consistently lay on their pigs and others do not". Honeyman and Kent (1997) have provided data from commercial farms in the USA using a Swedish group farrowing system on deep bedding straw, and reported piglet mortality ranged from 18.4-24.2% of live born piglets.

Two experiments by Marchant et al. (2000) investigated a pen farrowing system in the UK, involving five sows per group, but with individual farrowing pens, a communal "free" farrowing crate system and conventional crates. While stillbirths were lowest in the pen system compared to the crate systems, piglet mortality in the two group (pen) systems was higher than the conventional crates (25% v 13% of born alive). Recently, performance was compared by Kutzer et al. (2009) in a group farrowing pen, individual farrowing pen and conventional farrowing crates. Stillbirth rates were similar in the three systems. Overall deaths of live born pigs (to day 10) was lowest in the individual farrowing pen treatment (1.29/litter) compared to the group farrowing pens (1.58 piglets/litter) and farrowing crates (1.49 deaths/litter). While death due to crushing by the sow was highest in the group pen (1.13/litter), then individual pen (0.93), then crate (0.59/litter), deaths due to other causes was highest in the crate treatment (0.9/litter).

Dybkjaer et al. (2001) compared piglet mortality in litters of sows farrowed in crates and a Danish group farrowing pen ("get-away" pen, 6 sows per group) and reported 9.4% compared to 14.1% deaths of live born, respectively. In a subsequent experiment utilising the Danish "get-away" pens, Dybkjaer et al. (2003) reported piglet mortality in the pens was 10.9%.

Two experiments by Bunger (2002) compared piglet performance in a group farrowing system, with 8 sows per group, to individually housed sows that were restrained in a crate for farrowing then loose housed in individual pens (expt 1, 98 litters from 60 sows; expt 2, 189 litters of 70 sows). In experiment 1, piglets born in the group farrowing system were 19% heavier at 70 days of age than piglets from the individual housing system. In experiment 2, the stillbirth rate was halved in the group farrowed sows compared to the individually farrowed sows (in crates).

Recently, Li et al. (2010) reported a study investigating the performance of sows and litters in a group farrowing system (8 sows per group). Averaged over the 5 years of the study, piglet mortality was 22.6% and 8.9 piglets were weaned per litter. The authors reported that piglet mortality was reduced over the course of the five years and in the final year number weaned had risen to 9.2 piglets. A number of sow management changes were introduced during the study period which were presumed to reduce piglet mortality. These were:

1. To minimise disturbance, delay piglet processing until 3 days after the last sow in the room had farrowed;
2. To keep the bedding in the farrowing pens dry and clean, delay sow entry to the room (i.e. large straw-bedded pen plus 8 farrowing cubicles) until 2 days before the expected farrowing date rather than 7 days;
3. To keep the piglets in their separate farrowing cubicles until day 7 post-partum and ensure all piglets were present at nursing, improve the design of the entry to the doorway;
4. Promote effective stockperson skills, so that stockpeople became more adept at detecting and correcting problems. "Proper animal handling based on good animal-stockperson relationships, spending more time in the barn to closely observe sows and litters, promptly identifying and treating sick sows, and fostering piglets from problem sows when necessary, are all skills that improved in the labour force and likely contributed to reducing piglet mortality in this loose-farrowing system."

Piglet mortality was consistently higher in summer than in other seasons, and was thought to be associated with the straw bedding, which exacerbated heat stress. The authors thought that the heat stress may have influenced parturition (there was a tendency for higher stillbirth rate in summer) and during lactation, sows decreased their feed intake with the consequence that piglet live weight was lower at weaning perhaps reflecting poorer milk production and contributing to higher piglet mortality.

Interestingly, in their review loose farrowing systems for sows, Wechsler and Weber (2007) concluded that to ensure sow welfare, sows should not be group housed at farrowing. Instead, sow should be kept individually in "*sufficiently large pens structured for preference into nest and activity areas*".

Grouping Sows and Piglets in "Multi-Suckling" Lactation Pens

Wattanakul et al. (1997a) investigated the effect of farrowing sows in crates, then at about 2 weeks into lactation, half the sows and their litters were moved to multisuckling pens. Litters in the multisuckling system had reduced growth during the first week after mixing compared to litters that remained in their crates. Subsequently, piglet growth was similar to weaning at about 5 weeks. To examine this further, Wattanakul et al. (1997b) investigated the effects of mixing litters of piglets during lactation, and of moving sows to a different farrowing crate, on suckling behaviour and piglet growth. By mixing piglets and without moving the sows, only a brief disturbance to suckling behaviour occurred and there was no effect on piglet growth. However, relocating sows resulted in a high incidence of cross-suckling and reduced growth piglet. Weary et al. (1999) studied the pre- and post-weaning behaviour and growth of piglets that had access to a communal area from 11 days of age. Aggression was minimal after mixing. The number of suckling bouts per day decreased by about 10% following mixing, but this did not affect piglet weight gain compared to unmixed control litters. Piglets had access to creep feed in the study.

Outdoor Farrowing Systems

Pig raising was historically conducted as an outdoor pursuit (Thornton, 1990). Outdoor production systems offer advantages of lower capital outlay and portability. Hence, a proportion of pig production has persisted outdoors. Recently, with greater emphasis on organic and welfare friendly animal production, there has been a resurgence in interest in outdoor production, including outdoor farrowing of sows. Research has reflected this changing trend.

Edwards and Zanella (1996) reported piglet mortality for outdoor and indoor herds. Data were presented from two UK recording schemes involving more than 700 herds. The two schemes provide similar, but opposed, findings on whether piglet mortality was lower in outdoor compared to indoor (crate) systems. The overall piglet mortality for 1995 was about 18% of piglets. In the UK, Higgins and Edwards (1996) studied outdoor production with either individual sows per paddock or sows in groups. Piglet mortality in individual paddocks was 14.9% compared to 23.1% for the group paddock system.

In the USA, farrowing hut design was different to that developed by the UK outdoor pig industry. McGlone and Hicks (2000) compared piglet production and survival parameters from outdoor farrowed litters in two types of farrowing huts (English vs American design) and two crossbred genotypes (Camborough-15 vs 25% Mieshan). Preweaning mortality was lower in the English compared to American design farrowing huts (11.2% vs 19.7% of live born). There was no difference in preweaning mortality due to genotype.

The American-style huts were "boxes" that had vertical walls and which provided 3.32 m^2. The English-style huts were an arc design which provided 4.28 m^2, or 31% more floor area than the American huts. Neither hut design provided internal piglet saver rails.

The production of indoor sows and litters conventional farrowing crates were compared to outdoor sows and litters by Johnson et al. (2001). Outdoor sows were in groups in 0.4 ha paddocks; each sow had one farrowing hut. Behaviour of sows and litters was recorded by direct observation. Stillbirths were 8.3% in crates and 6.6% outdoors in huts, while piglet mortality was reported at 11.0% in crates and 11.8% outdoors. Outdoor sows and piglets were more active and showed a more diverse behavioural repertoire.

Two experiments by Gentry et al. (2002a, b) investigated growth and meat quality characteristics of pigs born outdoors (in huts) compared to indoors or reared indoors in different housing systems. Piglets from the two environments were transferred to two rearing environments at weaning – indoor and outdoor, with a cross-over design. Pigs born outdoors were significantly heavier throughout the growth period compared to indoor born piglets. Rearing environment did not influence growth. After adjusting for weaning weight (outdoor-born piglets were heavier), outdoor-reared piglets grew faster than indoor-reared piglets.

Wülbers-Mindermann et al (2002) compared sow and piglet characteristics and behaviour in indoor (individual) farrowing pens and an outdoor system with groups of 10 primiparous and multiparous sows with access to farrowing huts. The duration of parturition was longer indoors than outdoors for primiparous sows (243 v 157 min) but there was no difference in the number born alive. Piglet mortality in these litters was similar to day 4 of lactation (about 12%), but more piglets died indoors from day 5 to weaning. Overall preweaning mortality was 18.8% for indoor and 12.7% for outdoor primiparous sows.

Six sows were video recorded at their first two farrowings in huts by Vieuille et al. (2003). Two IR video cameras and a microphone were used to record sow and piglet activities within each hut. One half of all recorded incidents in which piglets were "trapped", and most (7 of 11) incidents of crushing, occurred within 12 hours of the first piglet's birth. Five of the six primiparous sows in the study behaved aggressively towards some piglets, but this did not lead to savaging. These aggressive mothers stood up after the birth of the first piglet and showed evident fear reactions when they neared the piglet. In incidents in which piglets were crushed, the sows seemed to have been irritated during the previous 10 minutes.

Sows in an outdoor system were tested by Held et al. (2006) for their responsiveness to a piglet scream test and a piglet handling ('piglet defence') test. Data were collected over 4 parities. The main finding from the research was that sow responsiveness in the two tests declined from first to fourth parity. Within parity, there was strong between-sow variation in responsiveness.

Baxter et al. (2009) aimed to identify behavioural and physiological survival indicators that are influential in outdoor systems that could provide additional information for use when selecting for piglet survival. The most important survival indices with respect to prenatal mortality (surviving v stillborn) were high ponderal index ($P<0.001$) or body mass index ($P<0.001$) in conjunction with being born earlier in the farrowing birth order. Birth weight ($P<0.001$) and rectal temperature 1 h after birth ($P=0.032$) were the most significant postnatal survival indicators.

Genetic Selection

Grandinson et al. (2002) analysed the farrowing records of 1,046 primiparous sows that had farrowed in farrowing pens at the Swedish University of Agricultural Sciences Lövsta research station between 1984-1999. Piglet mortality, including stillbirths, was 18% of total born. Heritabilities for crushing, stillbirth and total mortality were estimated and found to be low (0.01-0.15). Nevertheless, there were some interesting associations reported: The relationship between crushing and birth weigh was negative for both direct and maternal effects, indicating that sows with low-weight piglets were more likely to crush piglets. Recently, Roehe et al. (2010) estimated heritabilities for outdoor herds in the UK and reported the direct and maternal heritability of piglet survival at birth to be 0.21 and 0.15, and piglet survival during the nursing period to be 0.24 and 0.14, respectively.

Kleinbeck and McGlone (1999) compared three sow genotypes and their litters farrowed under conventional indoor versus outdoor housing, and concluded that some genotypes performed better indoors, whereas others performed better outdoors.

Design Criteria for Indoor Farrowing/Lactation Pen Systems to Minimise Piglet Mortality

In relation to non-crate farrowing accommodation, Cronin (1997) listed the important design features for reducing piglet losses in the Werribee Farrowing Pen, a non-crate farrowing system for use indoors and with individually housed sows and litters. The Werribee Farrowing Pen consisted of two areas, a nest area and a non-nest/sow activity area (Fig 3).

Figure 3: Photographs of the Werribee Farrowing Pen: Left, the original design circa 1990, and right, a version from 2002 (without bedding).

The features of the nest area were designed to attract the sow into the nest area as the preferred location for farrowing. The relevant design criteria to achieve this were:

- Privacy for the sow - sows be able to visually isolate themselves from other pigs. The nest area of the pen has 0.9 m high solid side walls enabling isolation. However, sows could see out the front of the nest above the 0.3 m high piglet barrier.
- Disturbance monitoring capability - sows should be able to monitor the approach of disturbances, i.e. from the nest, sows could see the area of the shed where the stockperson moved about for feeding and checking animals.
- Defendable space - sows should have the impression that the nest area was 'defendable' against intruders. The provision of a nest with solid walls on three sides and only allowing disturbance to come from the front, assists this requirement. Human activity at the rear of the nests should be minimal and of a quiet nature before farrowing and during parturition.
- Sow comfort - the nest area should provide a draught-free space. The bedding material on the floor of the nest area may provide a spongy layer for comfort on top of the sloping concrete floor.
- Nesting material - the nest area should contain bedding material which may focus the sow's attention on the nest area as a suitable site for farrowing. The nesting material may also stimulate pre-farrowing behaviour. Pre-farrowing behaviour should be encouraged, as previous research on sows in farrowing crates demonstrated the positive effects of stimulating pre-farrowing nesting activity for reducing the duration of parturition and improving the incidence of live births. The provision of nesting material was also thought to provide a thermal insulation layer for the piglets and reduce the slipperiness of the floor.

The internal fittings in the nest area were designed to promote piglet survival:

- Inward sloping panels - Attached to the inside of the farrowing nest, along the two sides and rear, were inward-sloping, solid panels. These panels were incorporated in the nest design 1) to assist the sow during posture changing as sows prefer to lie against sloping panels when changing from standing to lying posture, and 2) to provide a safe zone for piglets around the perimeter of the nest. These panels may also influence piglet behaviour and may therefore be important in reducing overlying.
- Piglet barrier - Across the front of the nest area, separating the nest from the non-nest area, was the 'piglet barrier'. The barrier in the prototype design was 0.3 m high and made from heavy galvanised steel, curled over at the top. The curled top allowed sows to step over it from either side, while preventing piglets from climbing out of the nest as the top curled into the nest. The barrier was removed once the piglets reached 7 days of age.
- Heated rear creep area - The rear of the nest area was sectioned off from the sow as a creep area for the piglets, and included a thermostatically-controlled heater. Newborn piglets require a radiant temperature of about 34°C. While this temperature could be satisfactorily provided for piglet comfort most of the time, in hot weather the day time temperature could exceed 34°C. The consequence would be that piglets do not use the creep area, and instead are more likely to be found away from the creep area in the sow zone, where overlying risk increases. The use of a thermostatically-controlled heater was therefore considered very important for hot weather. In the event that the overnight

temperature falls due to a cold front moving through, the creep heater would switch on and provide warmth for the piglets. The operating principle of the heated creep area was that the protected (creep) area at the rear of the nest must remain attractive for piglets for resting/sleeping at all times. To avoid over-heating in hot weather, the thermostat control on the heater should be set to 25°C.

Subsequently, Baxter et al. (in press) presented summary lists of design recommendations to meet the biological needs of sows (Table 8) and piglets (Table 9) during farrowing and lactation.

Table 8: Summary of design recommendations to meet the biological needs of sows during farrowing and lactation. Copied from Baxter et al. (in press)

Component of system	Biological specification	Recommendations
Space*	Increased activity for nest-site seeking	4.9 m^2 (minimum recommendation based on combining two areas the sow can turn around in – see below)[b]
	Hygiene – dunging space	Separate area from nest and feed sites[a]. Interaction with air temperature and floor properties
	Feeding and foraging	Separate area from nest and dung sites[a]
	Turn-around nest space for piglet inspection and gathering behaviour	Floor space = 2.44 m^2, planar space = 3.17 m^2 (minimum)[a]. Further research needed for unimpeded turning by the sow
	Lateral lying and parturition	2.79 m^2 (minimum)[a]
	Thermal comfort via posture changes	2.44 m^2 allows at a minimum getting up and lying down posture changes[a]
	Nest-departure	Separate area from nest site[b]
	Social contact	Full contact only recommended when mixing familiar groups[b]. Space dependent on group size and needs 'clever' design to accommodate avoidance behaviours[a]. Further research needed on 'personal space' for group suckling behaviour
	Gradual separation from piglets and controlled nursing	Separate space unattractive to the piglets[b]. Interaction with air temperature and floor properties
Substrate	Nest-building – carrying and manipulating	2 kg long stemmed straw (minimum)[a] accessible to the sow. Further research needed for alternative substrates with similar properties
	Complete nest	2 kg long stemmed straw and branches (minimum)[a]
	Udder comfort	Further research needed, interaction with floor properties
	Thermal comfort during nest building	Further research needed to determine sow temperature preferences during nest building
	Thermal comfort during parturition	Deep bedding 10 to 12 cm[a], interactions with floor properties and ambient temperature
	Foraging material	Further research needed on suitable materials and required amount
Walls	Enclosure/isolation of nest	Three solid-sided walls (cul-de-sac)[b]
	Darkness	Dark walls to simulate burrow[b]
	Visual and physical contact with non-litter pigs	Vertical barred area outside nest with void wide enough to allow at least nasal contact between pigs for social integration (minimum)[b]
	Supported posture changes	Solid sloped or vertical walls[a]
	Lack of disturbance	Further research needed to determine benefits of providing a quiet area
Flooring	Nest building – digging, rooting and hollowing	Malleable (e.g. earthen) or solid to accommodate deep substrate[a]
	Nest building and parturition	Solid to accommodate substrate[a]
	Thermal comfort during nest building	Further research needed to determine sow temperature preferences during nest building. Temperature differentials in separate areas allowing choice[b]
	Thermal comfort during parturition	High thermal resistance, for example, rubber matting or deep substrate. Temperature differentials in separate areas[a]. Further research needed for recommendation of localised temperature
	Thermal comfort during lactation	Low thermal resistance, for example, metal. Temperature differentials in separate areas[b]
	Physical comfort – avoiding injury, promoting suckling behaviour	Non-slip surface[a] Minimal abrasiveness, for example, rubber matting or plastic-coated metal[a] Solid to avoid teat injuries[a]
	Hygiene	Slatted area[a] Gradation of floor with slope away from lying area[b]. For example, 10% slope for drainage
General	Thermal comfort	Ambient temperature 12°C to 22°C[a], interactions with substrate and flooring
	High feed intake	See space and thermal comfort

[a]Recommendations derived from one or more specific references.
[b]Recommendations based on synthesising and interpreting the literature reviewed.
*Space calculations based on an 'improved' sow weighing 350 kg.

Table 9: Summary of design recommendations to meet the biological needs of piglets during farrowing and lactation. Copied from Baxter et al. (in press).

Component of system	Biological specification	Recommendations
Space[c]	Parturition	Length of sow and piglet (2.42 m) × width of sow lying laterally and ventral piglet (1.15 m) = 2.79 m^2 (minimum)[a]
	Udder access for suckling throughout lactation	Depth of sow (0.71 m) + length of 4 to 5 week old piglets (0.50 to 0.60 m) = 1.21 to 1.31 m (minimum)[a]
	Protection, safe lying area for parturition and nest occupation	Separate space inaccessible to the sow e.g. 0.80 m^2 per 10 to 12 neonates[a]
	Protected lying area during lactation	0.97 m^2 (minimum) – 2.32 m^2 (maximum) for 14, 4-week-old piglets[a]
	Area for feed trough to introduce creep feed	Provide in area inaccessible to the sow, interacts with above[b]
	Hygiene	Separate area for dung site, interacts with flooring[a]
Substrate	Foraging, nutritional development	Earth-like materials (e.g. peat)[a]
	Enrichment, social development	Further research needed on quantity. Novelty requires fresh input daily. Complex materials (e.g. branches) preferred[b]
	Thermal comfort during parturition	2.5 cm of straw[a], interacts with flooring
	Physical comfort	Further research needed, interacts with thermal comfort and flooring properties
	Protection	Deep bedding – 10 to 12 cm[a], interacts with flooring
Walls	Protection from sow posture changes	Escape zones at all pen walls[b]
	Social contact (visual and physical)	Vertical barred area (minimum)[b]. Further research needed to determine best method to mix pre-weaning.
	Hygiene	Solid walls (at least at bottom of penning) separating other litters during first 7 days of life[b]
	Thermal comfort	Solid walls in lying area of material to limit heat loss via radiation[b] – interacts with substrate and flooring
Flooring	Thermal comfort during parturition and first 24 h of life	High thermal resistance[a] – for example, rubber matting or deep substrate (see above) or under-floor/localised heating (see General)
	Thermal comfort during lactation	High thermal resistance[b] – for example, rubber matting or deep substrate (see above) or under-floor/localised heating (see General)
	Physical comfort – avoiding injury, promoting suckling behaviour	Solid flooring with minimal abrasiveness and well maintained (e.g. rubber matting or specialised screed with non-slip properties), interacts with substrate
	Protection from fatal crushing by the sow	Malleable flooring[b] interacts with deep substrate
	Hygiene	Slatted flooring with void width no more than 10 mm and rounded edges[a]. Interacts with temperature (see General)
General	Health – treatment for injuries, vaccines, etc.	Safe area for handling required to ensure piglet health needs, interacts with space[b]
	Promote weaning, reduce nutritional stress and encourage increased feed and water intake	Suitable solid food, inaccessible to the sow – interacts with space and substrate. Provide feed tray with sufficient space to allow social facilitation[a]. Provide water drinker with upward angled bite nipple close to floor[a]
	Thermal comfort	Localised heat source set at thermo-neutral temperature (e.g. 34°C at birth) – interacts with substrate[a]
	Hygiene	Temperature differentials to encourage dunging outside of nest site – interacts with flooring[b]

[a]Recommendations derived from one or more specific references.
[b]Recommendations based on synthesising and interpreting the literature reviewed.
[c]Space recommendations for an 'improved' sow weighing 350 kg and an 'optimum' birth weight piglet of 1.6 kg

8. Implications & Recommendations

New indoor, individual farrowing pen systems for sows and litters, for example, require extra floor space and construction complexity compared to farrowing crates. Thus, greater capital investment will be required. To maintain return on investment, producers will need to wean more piglets per litter. This could be achieved through improved piglet survival and, or larger litter sizes. An alternative strategy might be to establish a lower capital investment facility in which it is accepted that fewer piglets will be weaned. Research is clearly needed to evaluate a range of alternative systems under Australian conditions, from low-cost to high-tech (and cost?), to provide producers with sound economic data as to capital investment required, costs for operating the systems, productive outputs and ease of operation. If the change from farrowing crates to an alternative system involves acceptance of lower production goals, for example fewer piglets weaned per litter and an acceptance of higher piglet mortality, industry may receive criticism from welfare groups.

The literature indicates that comparable levels of piglet survival, one of the main economic and welfare parameters for evaluating alternatives to farrowing crates, have been achieved in most non-crate farrowing systems. However, the lack of consistency in reporting "good" findings suggests we lack understanding of the factor(s) within the "successful" farrowing systems that contributed to their success. A key difference between farrowing sows in a confined, crate environment compared to a "loose" pen with bedding, is that the combination of space and bedding stimulate the sow's natural pre-farrowing behaviour. If we provide the sow with a stimulating (enriched) environment, then it is essential to provide the sow with an appropriate space in which to farrow, that also contains design features to promote piglet survival. Further, the sow and litter need to be managed correctly to facilitate identification and rectification of problems and as soon as possible.

A major gap in knowledge concerns the selection and training of stockpeople to manage sows and litters in non-crate farrowing systems. The stockperson's level of understanding of how sows and piglets behave in the particular non-crate system, and the stockperson's ability to recognise and correct problems, seem to be essential for the success of a system. Thus, while specialist training and support information for stockpeople working with farrowing sows will be initially required, a program to identify (i.e. select) stockpeople with appropriate qualities may be needed.

Straw seems to provide both behavioural and nutritional benefits for the sow. These effects also appear to benefit piglets indirectly, through shorter parturition time, reduced incidence of crushing by the sow and better suckling behaviour. An important issue for Australia associated with use of straw bedding concerns the risk of contributing to heat stress on sows in summer. A gap in knowledge therefore is the optimum quantity of straw provided under Australian (summer) conditions.

The literature suggests there is a minimum size for farrowing pens (and huts). If farrowing pens are too small or too large, piglet survival seems to be adversely affected. Thus, the optimum floor area and pen dimensions need to be identified.

The relationship between pre-partum nest-building behaviour and the duration of parturition is not well researched. Limited information suggests an inverse relationship, that is, as the amount of nest-building behaviour performed by the sow increases (e.g. through stimulation with nesting material), the farrowing process proceeds faster and with fewer complications. The potential benefits of faster farrowing time include reduced intra-partum stillbirths and possibly a lower incidence of unviable live born piglets.

The relationship between pre-partum nest-building behaviour and the level of care taken by sows when changing posture in the days post-partum is not well researched. Limited information suggests that sows which perform more nest-building behaviour are less likely to crush piglets.

A major risk to piglets in the neonatal period is that they tend to remain at the sow's udder, thus risking crushing and chilling. This is despite providing a "safe", heated creep zone for the piglets. However, the biology of the pig is such that the neonates are strongly attracted to the udder. A gap in knowledge in non-crate systems is how to encourage neonates to move away from the udder to a "safer" location. Related to this is the possibility that by stimulating sows to perform more pre-farrowing nest-building behaviour, the sows become more-careful mothers.

Recent information in the literature suggests that lower weight piglets are more likely to be overlain. Perhaps this is correlated with poor foetal development and is not a live weight issue per se? A gap is knowledge therefore concerns the development of the foetal pig and the interaction between viability, behaviour and survival in non-crate systems.

An important gap in knowledge is how to preventing sows and piglets from dunging in the wrong location. Farrowing pens typically have a larger solid floor area compared to crates. Understanding is lacking on how to stimulate sows to dung on the slatted floor area of pens. For piglets, a recent innovation from Denmark is the incorporation of a curved concrete join between the floor and the wall to stop piglets dunging in corners of farrowing pens.

Many of the farrowing pen systems reported in the literature have been designed for use in cool climates. The systems rely, at least in part, on controlling the behaviour and resting location of the sow and piglets through manipulating differentials in temperature in different parts of the pen. A very important knowledge gap for Australian conditions is how these systems will work in hot (and humid) weather. Further, if the issue is addressed by inclusion of cooling mechanisms such as fans or sprinkler systems, how will this effect piglet survival and growth? In addition, the use of straw seems to exacerbate the problem and may lead to poorer hygiene conditions for piglets.

The selection for piglet survival at birth and to weaning has been shown to be feasible in non-crate systems. A gap in knowledge however, concerns the welfare outcome for piglets if genetic selection for very large litter size occurs. Selection for very large litter size is occurring in Scandinavia, with a corresponding increase in litter weight. A gap in knowledge therefore, concerns how this situation will affect piglet viability, growth and survival? There will also need to be an increase in milk production from the sow to feed the larger litters.

9. Intellectual Property

There are no intellectual property issues associated with this project report.

10. Technical Summary

A review of the literature on alternatives to farrowing crates was conducted. A range of non-crate systems have been investigated and reported on in the literature, from indoor to outdoor systems involving single housing and group housing of sows. Piglet survival is one of the main economic and welfare parameters used for evaluating alternatives to farrowing crates. The literature however, lacks consistency in reporting "good" findings regarding piglet mortality, suggesting lack of understanding of the factor(s) within the "successful" farrowing systems that contributed to their success. A key difference between farrowing sows in a confined, crate environment compared to a "loose" pen with bedding, is that the combination of space and bedding stimulate the sow's natural pre-farrowing behaviour. If we provide the sow with a stimulating (enriched) environment, then it is essential to provide the sow with an appropriate space in which to farrow, that also contains design features to promote piglet survival. Further, the sow and litter need to be managed correctly to identify problems and to rectify them as soon as possible. It is clear that the stockperson's level of understanding of how sows and piglets behave in the particular non-crate system, and the stockperson's ability to recognise and correct problems, seem to be essential for the success of a system.

The use of straw bedding for pigs in Australia has been contentious due to its high cost (at times), low availability and requirement for increased labour to remove it once fouled in pens. However, straw seems to provide both behavioural and nutritional benefits for the sow. These effects also appear to benefit piglet viability and survival, and reduce the incidence of crushing by the sow and improve suckling behaviour. An important issue for Australia associated with use of straw bedding concerns the risk of contributing to heat stress on sows in summer. Recent information in the literature suggests that lower weight piglets are more likely to be overlain. Perhaps this is correlated to poor foetal development and is not a live weight issue per se, suggesting the need to research the development of the foetal pig and the interaction between viability, behaviour and survival in non-crate systems. A related risk to piglets in the neonatal period is that they tend to remain at the sow's udder, thus risking crushing and chilling. This is despite providing a "safe", heated creep zone for the piglets. However, the biology of the pig is such that the neonates are strongly attracted to the udder.

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12. Publications Arising

Payne H, Cronin GM (2010) An Australian perspective on non-crate farrowing systems. In: *Proceedings of the Animal Welfare Science Centre Seminar, "Alternative Farrowing Systems: Identifying the Gaps in Knowledge"*, 15h September 2010, DPI Attwood, p. 3.