Automatic oestrus detection by modelling eating behaviour of group-housed sows in electronic sow feeding systems

Master Thesis
by

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Abstract

In recent years much attention has been paid to animal welfare in Denmark, resulting in extension of production systems for group-housed sows. These new production systems combined with constrains in production have emphasized the need for improving management routines in group-housing systems. Normally daily management is focused on physical condition, general health and oestrus detection. In electronic sow feeding systems, especially the daily management of general health and oestrus detection is complicated due to the difficulty in monitoring individual sows.

Reports of decreased voluntary feed intake during the week of oestrus seem to suggest the existence of a correlation between oestrus and appetite, caused by increased blood level of oestrogens prior to standing oestrus. By modeling eating behaviour of individual sows in electronic sow feeding (ESF) systems, it is investigated whether deviations in eating behaviour can be used in oestrus detection, in order to improve management routines concerning oestrus detection.

Since sows in ESF systems normally are fed restrictive, a decreased appetite does not necessarily affect daily feed intake, and it seems more appropriate that a decreased appetite might affect the over all eating behaviour. However modeling eating behaviour is complicated since eating behaviour can be described by several properties, and is additionally affected by external factors. In this study eating behaviour is described by two properties, the time of first feeding visit and daily feed intake in each feeding cycle.

In modeling of eating behaviour the model have to be able to handle random noise as well as abrupt and gradual changes in eating behaviour. Two Multi-Process Dynamic Linear Models (MP-DLMs), consisting of two Dynamic Linear Models describing a normal and an outlying observation respectively, are used in modeling each of the properties of eating behaviour. The combining is effected by discrete probability mixture, that directly specifies the probability of deviations in eating behaviour in each feeding cycle. In order to increase certainty of the identified deviations, a back step filtering is applied to the MP-DLMs.

In using eating behaviour to identify oestrus it seems possible that oestrus affects eating behaviour by decreasing appetite and causes deviations in both time of first visit and daily feed intake. However individual variability in sows' eating behaviour might be responsible for deviations occurring independently of oestrus. The applied models seems unreliable in identifying oestrus which is thought to be caused by model insufficiencies as well as individual variability in sows' eating behaviour.

Sammendrag

I de seneste år har begrebet dyrevelfærd været genstand for stor opmærksomhed i Danmark, hvilket også har haft betydning for svineproduktionen og ført til udbredelse af produktionssystemer, der i højere grad end tidligere tilgodeser grisenes velfærd. Disse nye produktionssystemer samt produktionsbegrænsninger har øget behovet for en effektiv produktionsstyring. I produktionssystemer med elektronisk so fodring især management fokuseret på søernes sundhed samt forekomsten af brunst besværlig på grund af behovet for dagligt tilsyn med de enkelte søer.

Faldende foderoptagelse hos søer og gylte i forbindelse med brunst synes at indikere en sammenhæng mellem brunst og appetit, forårsaget af stigning i blodets koncentration af østrogener. Gennem modellering af de enkelte søers ædeadfærd undersøges i nærværende projekt muligheden for at anvende afvigelser i søernes ædeadfærd til detektion af brunst, for derved at kunne forbedre det daglige management.

Da søer i systemer med elektronisk so fodring ofte fodres restriktivt vil en nedsat appetit ikke nødvendigvis medføre faldende foderoptagelse, men derimod ændringer i ædeadfærden. Modellering af ædeadfærden er dog vanskelig på grund af en lang række egenskaber der til sammen udgør ædeadfærden. I dette projekt er ædeadfærden modelleret med to egenskaber, tidspunktet for første foderbesøg og daglig foderoptagelse.

I modellering af ædeadfærden skal den valgte model besidde egenskaber der gør at både tilfældig variation såvel som gradvise og pludselige ændringer i ædeadfærden kan håndteres. To Multi Proces Dynamisk Lineære Modeller er benyttet til modellering af hver af de to egenskaber. Hver af Multi Proces modellerne er sammensat af to Dynamisk Lineære Modeller, der beskriver en normal henholdsvis en afvigende observation. Kombinering af de to dynamiske lineære modeller sker gennem sandsynligheder for forekomsten af normale og afvigende observationer. For at øge sikkerheden på identificering af afvigende observationer foretages en tilbage filtrering af sandsynlighederne for de enkelte observationer.

Ved anvendelse af søers ædeadfærd til detektion af brunst, synes der at være en sammenhæng mellem forekomsten af brunst og ændringer i søernes ædeadfærd. Imidlertid forekommer der tilsyneladende betydelig individuel variation i søernes ædeadfærd og forårsager afvigelser i ædeadfærden der synes uafhængige af brunst forekomsten. De anvendte Multi Proces Dynamisk Lineære Modeller synes således for upålidelige til detektion af brunst, hvilket menes at være forårsaget af utilstrækkeligheder i de anvendte modeller samt variation i individuelle søers ædeadfærd.

Preface

The present project is prepared as a master thesis of the general M.Sc Programme in Agricultural Science at the Royal Veterinary and Agricultural University, Department of Animal Science and Animal Health.

The author wishes to thank supervisor Anders Ringgaard Kristensen, Department of Animal science and Animal Health, Royal Veterinary and Agricultural University and co-supervisor Thomas Nejsum Madsen, The National Committee for Pig Production, DANISH BACON AND MEAT COUNCIL, for their support and comments during elaboration of the project. In addition thanks to The National Committee for Pig Production, DANISH BACON AND MEAT COUNCIL for the disposal of recordings of sows' use of electronic feed stations, to Flemming & Jens Peter Risbjerg for their helpfulness and permission to record the sows' use of feed stations in their herd, and to those who have applied comments and encouraged this study.

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Contents

Chapter 1

General introduction

In recent years much attention has been paid to animal welfare in Denmark and new production constrains have been introduced in order to increase animal welfare. In several countries confinement of pregnant sows has additionally been banned in order to improve welfare, resulting in stalls and tethers being replaced by new production systems. One of these new production systems includes electronic sow feeding (ESF) where group-housed sows are fed individually by electronic feed stations (Jensen et al., 2000).

The extension of these new production systems combined with the constrains in production have emphasized the need for improvement of management routines used in commercial herds. In particular the manager's skills and effort in observing changes in animal behaviour becomes of decisive importance in order to interfere in due time.

The daily management of pregnant sows is to a large extend focused on physical condition, general health and oestrus detection of the individual sows. The individual feeding of sows using ESF enhances the possibilities of managing the physical condition of the sows compared to other loose housing systems, but management concerning general health and oestrus detection is still complicated and very time consuming due to the difficulty in monitoring individual sows every day. Detection of oestrus is of major concern in pig production in order to obtain a punctual mating and reduce the farrowing interval.

In an early study Friend (1971) investigated the voluntary feed intake on a weekly basis of 12 gilts and 7 sows fed *Ad libitum*. During the week of oestrus a significant decrease in feed intake was reported irrespective of expressing feed intake in terms of dry matter, crude protein or energy (Friend, 1971). In a later experiment including 9 gilts similar results were found with an average decrease in weekly feed intake, from 23.56 ± 0.384 kg in weeks between successive oestrus periods to 19.90 ± 0.38 kg in weeks in which oestrus occurred (Friend, 1973). von Willeke and Metges (1984) supported this by suggesting an adversely effect of oestrus on appetite in gilts, and decreased feed intake around oestrus has in addition been reported both in cows (Walton and King, 1986; Trout et al., 1998), as well as ewes and goats (Forbes, 1995).

The effects of oestrus on appetite is suggested to be caused by oestrogens (Forbes, 1995). Infusion of oestradiol has been shown to decrease feed intake in sheep and goats both by inhibiting the hypothalamus and change the metabolic activity of peripheral tissues (Forbes, 1986). By the increased levels of blood oestrogens prior to oestrus in pigs (Rojanasthien, 1988; Whittemore, 1993; Forbes, 1995) it seems likely that decreases in feed intake in relation to oestrus could be caused by oestradiol. Oestradiol concentration increases gradually and continuously from 6 hours after weaning, starting in the follicular fluid and evolving into the utero-ovarian vein 24-48 hours after weaning and the jugular vein 60-85 hours after weaning (Einarsson et al., 1998), until it peaks approximately 24 hours before standing oestrus (Whittemore, 1993). Since increases in oestradiol occur prior to standing oestrus it seems possible to use decreases in feed intake as an indicator of oestrus.

Sows using electronic feed stations are typically fed restrictively in accordance to their physical condition, and a decreased appetite does not necessarily affect feed intake, depending on the severity of the decreased appetite as well as the ration size. Since the sows, at least to some extend, are offered the possibility to eat when they want to, it seems likely that a decreased appetite more appropriately is expressed as changes in the over all eating behaviour. This implies that a decreased appetite i.e. could be expressed as changes in time of feeding or in the duration of feeding. In addition feed ration could be split into more feeding visits, rather than the frequent occurrence of sows eating all of their ration in a single visit as suggested by Bengtsson et al. (1984). As well the number of non-feeding visits could be decreased, as these visits are suggested to be motivated by social facilitation (Hunter et al., 1988) or by searching for left feed from the previous sow (Olsson et al., 1992).

Normally a large amount of data is produced in pig production and these data form the basis of the manager's decisions. Any benefit from the data requires that they are processed to information or beliefs in the true state of the animals, and afterwards used in decision-making at the operational and tactical level. However only simple data processing methods are often applied, resulting in a delay in the information derived from data. In order to obtain useful information to be used in decision-making in herd management faster, there is a lack of good applications for processing the data. One way to enhance the herd management in ESF systems is by an increased use of information technology in data collecting and processing.

The use of sensors and electronic ear tags have made a whole new range of registrations potentially available to the farmer. By the automatic identification of individual sows in the feed stations, it becomes possible to map the eating behaviour of group-housed sows in detail, which alternatively i.e. has to be done by studying video recordings or by the LUCIFIR system described by Forbes (1995). With these enhanced possibilities in automatic monitoring of the individual sows' behaviour it becomes possible to map the eating behaviour of individual sows intensively. By monitoring eating behaviour of individual sows it is in the present study investigated whether deviations in eating behaviour can be identified and related to the occurrence of oestrus.

The aim of the study is to meet the need of enhanced management systems concerning oestrus detection in electronic sow feeding systems by analyzing the possibilities in automatic identification of oestrus by modelling of eating behaviour.

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Chapter 2

Modeling eating behaviour

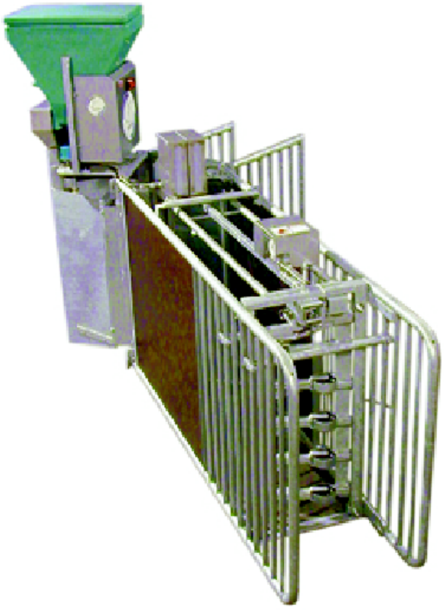
In modeling of eating behaviour the first problem that arises is how to model eating behaviour, since eating behaviour is composed of several individual actions starting by initiation of feed seeking and ended by termination of eating. These actions can be described in more or less details comprising both the level of the individual muscles as well as the term eating behaviour (Manning and Dawkins, 1992) and it appears that the term behaviour is qualitative rather than quantitative. Quantification of eating behaviour is however a necessary step, but it is not obvious how to do this. In this project eating behaviour is expressed by a number of properties that in it self are quantitative and separately contributes eating behaviour.

2.1 Monitoring visits to the feed stations

In ESF systems the feeding computer controls the feeding of the individual sows by electronically identifying sows. This automatic monitoring of every visits to the feed stations throughout the feeding cycle applies detailed information of the entire group's as well as the individual sows' eating behaviour and use of feed stations. On a commercial farm with 400 sows these registrations of the feed station use have been recorded in order to obtain information of the sows' eating behaviour. Gestation house comprised two pens for dynamic groups of approximately 150 sows using electronic NEDAP feed stations operated by ear tag responders, cf. Figure 2.1. The feed stations had forward exits leading the sows away from the feeding area.

Data recording have been performed successfully in three consecutive periods of approximately 70 days. In the two first periods the sows were split up according to their identification number with odd (group 1) and even (group 2) numbered sows in each of the two pens. Sows in group 1 had access to 3 feed stations

Figure 2.1: NEDAP feed station operated by ear tag responder.



whereas group 2 only had access to two feed stations. In the third period sows were split up according to their parity with gilts and first parity sows in group 1 and older sows in group 2. Additionally feed stations were turned off at 14:00 in period 3, in order to prevent sows accessing feed stations until a new feed cycle was started. In Table 2.1 some of the characteristics in describing eating behaviour of the entire groups are summarized.

From the table it is seen that more feeding visits occur than the number of sows in each group, implying that some of the sows do not eat all of their feed ration in a single visit. These sows make out around 20 pct. of the sows which is likely the finding of Eddison and Roberts (1995), who found that 79 pct. of the sows were eating all of their feed in a single visit. Further the total number of visits within each group markedly exceed the number of feeding visits indicating a frequent occurrence of non-feeding visits as found by Edwards (1985); Beckett et al. (1986); Hunter et al. (1988); Edwards et al. (1988) and Olsson et al. (1992). Although all of the sows in a group have been found to perform non-feeding visits (Hunter et al., 1988), some sows seem to be extremely active in performing non-feeding visits (Hunter et al., 1988; Edwards et al., 1988), leading to disturbances in eating behaviour and decreases capacity of feed stations. In studying the effects of feed station design on eating behaviour forward exits (Edwards et al., 1988)

Table 2.1: Eating behaviour characteristics of the entire group of sows. In period 1 and 2 the groups were formed by odd and even numbered sows respectively. In period 3 group 1 was formed by gilts and 1st parity sows and group 2 by older sows.

	Period 1 15/7-99 - 22/9-99		**Period 2** 29/1-00 - 17/4-00		**Period 3** 24/7-00 - 6/10-00	
	Group 1 Mean (STD)	Group 2 Mean (STD)	Group 1 Mean (STD)	Group 2 Mean (STD)	Group 1 Mean (STD)	Group 2 Mean (STD)
Number of sows	111.25 (3.16)	110.58 (8.22)	124.23 (11.08)	133.97 (7.94)	142.79 (9.70)	160.46 (10.49)
Total visits	1030.54 (169.72)	1022.04 (247.37)	979.03 (125.12)	1054.43 (166.04)	947.38 (109.61)	1045.60 (155.32)
Feeding visits	184.88 (90.84)	180.96 (77.17)	156.02 (14.53)	179.54 (27.41)	184.76 (31.31)	218.91 (43.74)
% sows eating in 1^{st} visit	76.58 (16.83)	72.25 (17.96)	83.88 (6.98)	77.37 (9.72)	81.39 (8.86)	78.02 (8.11)

and computer controlled feed stations (Olsson et al., 1992) have been shown to decrease the duration of non-feeding visits as well as moveable troughs have been noted to decrease both duration and number of non-feeding visits (Olsson et al., 1992).

2.2 Eating behaviour of individual sows

The detailed registration of the individual animal's eating behaviour resulted in a total number of registrations on a single day between 1223 and 9894 with a mean of 4048 for both of the groups. This huge number of registrations implies that each sow visits the feed stations several times a day although the registrations cover both the start of new visits as well as registrations within a visit. Several properties of eating behaviour, that in some how relates to appetite, can be derived, i.e. time of visits, daily feed intake, number of visits, number of feeding visits and feeding time. This detailed information in addition might comprise information on diurnal patterns, which however have not been paid attention in this project.

In studying stability of the derived properties time series of 3 different sows are used. The sows have been selected to illustrate some of the differences in the properties of eating behaviour and more or less stable patterns is revealed. Figure 2.2 shows the time of all visits in each feeding cycle of three sows of different parity, expressed as time since beginning of the feeding cycle. Beginning of feeding cycle (0:00) is defined by the first sow eating after feed has become available. Each mark in the figure represents a single visit and the differences in total number of visits in each feeding cycle between the sows are obvious. However no stable pattern of eating behaviour is revealed. The information on eating behaviour shown in Figure 2.2 only comprise part of the pregnancy of the sows, which is caused by unsuccessful data recording.

If only time of first feeding visit in each feeding cycle are shown (Figure 2.3), far more stability seems to occur. In example sow 907 (Figure 2.3 (b)) shows a high degree of stability in time of first feeding visit, whereas the other sows (Figure 2.3 (a) + (c)) show hardly as stable patterns. In spite of the gradual changes occurring in time of first feeding visit, some form of stability however seems evident and only few abrupt changes or deviations occur, if any. Studying time of first feeding visit of the individual sows, an interval between two consecutive feeding cycles of less than 24 hours in the period following introduction is often seen, resulting in earlier first visits. This period of adaptation could be a result of the new sows' integration and adaptation to the social hierarchy as described by Moore et al. (1993) and is often succeeded by a more stable pattern with approximately 24 hours between two consecutive feeding visits as suggested by Edwards et al. (1988).

Another property of eating behaviour derived from the registrations is the daily feed intake. Since sows in electronic feeding systems normally are fed restrictive, daily feed intake is markedly affected by the defined feeding norm in the feeding computer. In feeding pregnant sows The National Committee for Pig Production, The Danish Bacon and Meat Council recommends that the daily feed allowance is increased twice during pregnancy provided that the sow is in acceptable physical condition. This results in a relatively stable feed intake for each sow as shown in Figure 2.4, normally including two level shifts. In the experiment feed allowance was only increased once during pregnancy, resulting in a single level shift as seen in Figure 2.4 (a) and (b). Although it might be different, it is assumed that the daily feed intake equals the amount of feed fed, since information on feed left in the feed stations by the individual sows has not been available.

In relation to a decreased appetite, the time spent eating all of the daily feed ration of the individual sows might also be of interest. In Figure 2.5 feeding time in each feeding cycle is shown, where feeding time is defined as the time from the first portion is fed until the last portion is fed. Considering the approximate 9 minutes theoretical time of feed delivery of a 2.6 kg ration (22 seconds between consecutive feeding of 100 g feed) and the high proportion of sows eating all of the daily allowance in a single visit (Table 2.1), very stable patterns must be expected. Studying Figure 2.5 such stability is also seen, but for all of the sows shown, several deviations occur throughout the period of data recording. If feeding time markedly exceeds the theoretical time of feed delivery, this necessarily

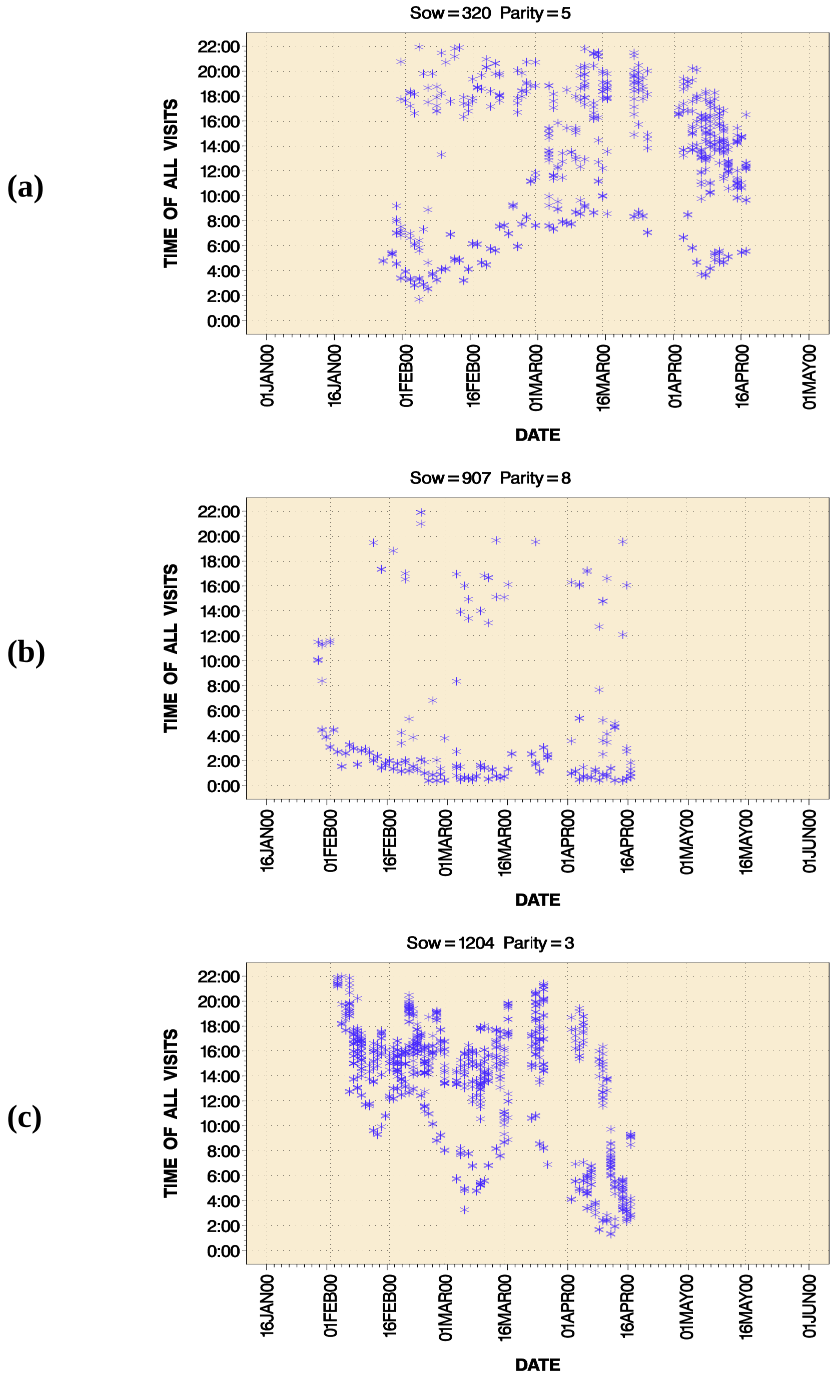


Figure 2.2: Time of all visits in each feeding cycle expressed as time since beginning of feeding cycle of three different sows. No stable patterns seems obvious.

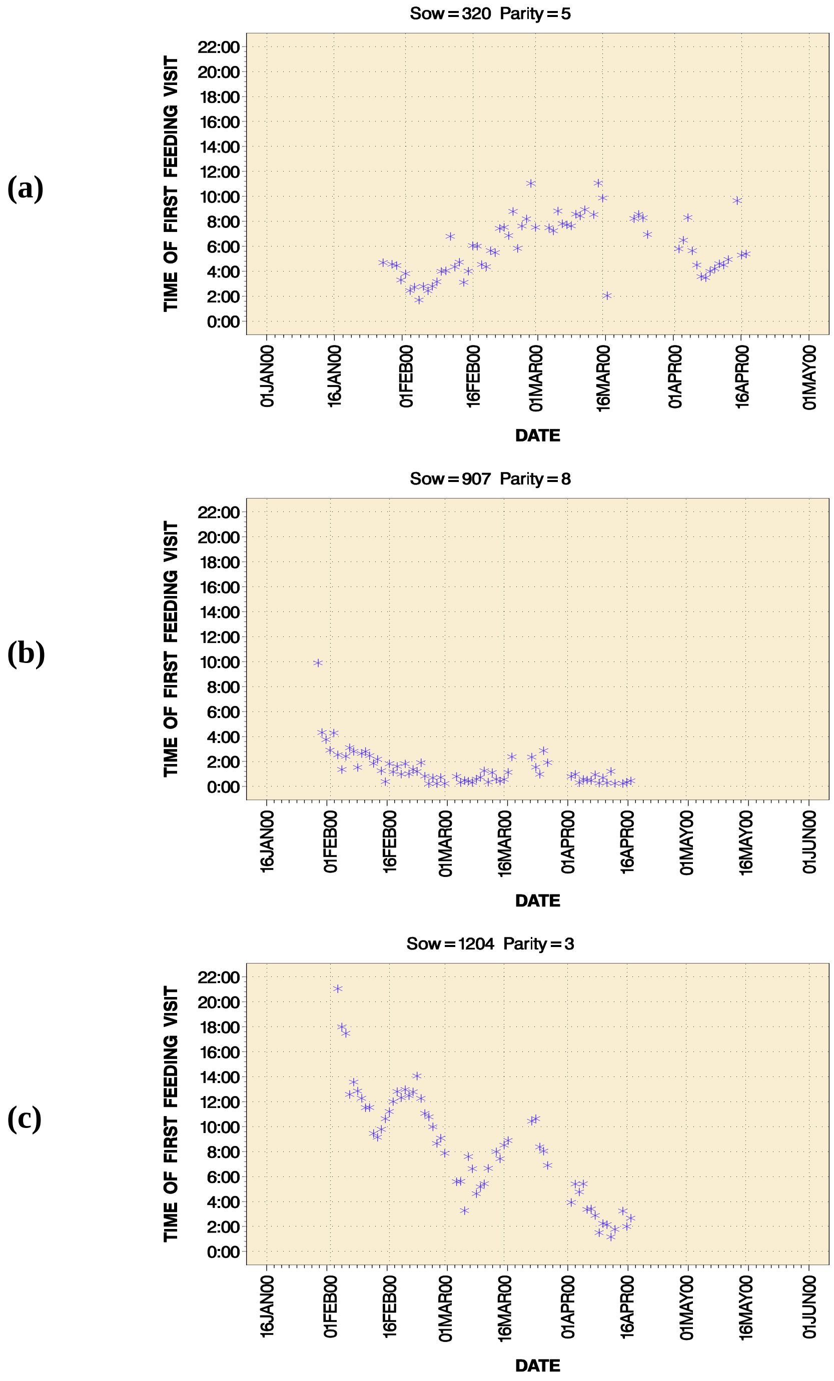


Figure 2.3: Time of first feeding visit in each feeding cycle expressed as time since beginning of feeding cycle. The time of first feeding visit seems rather stable although gradual changes occur for some sows.

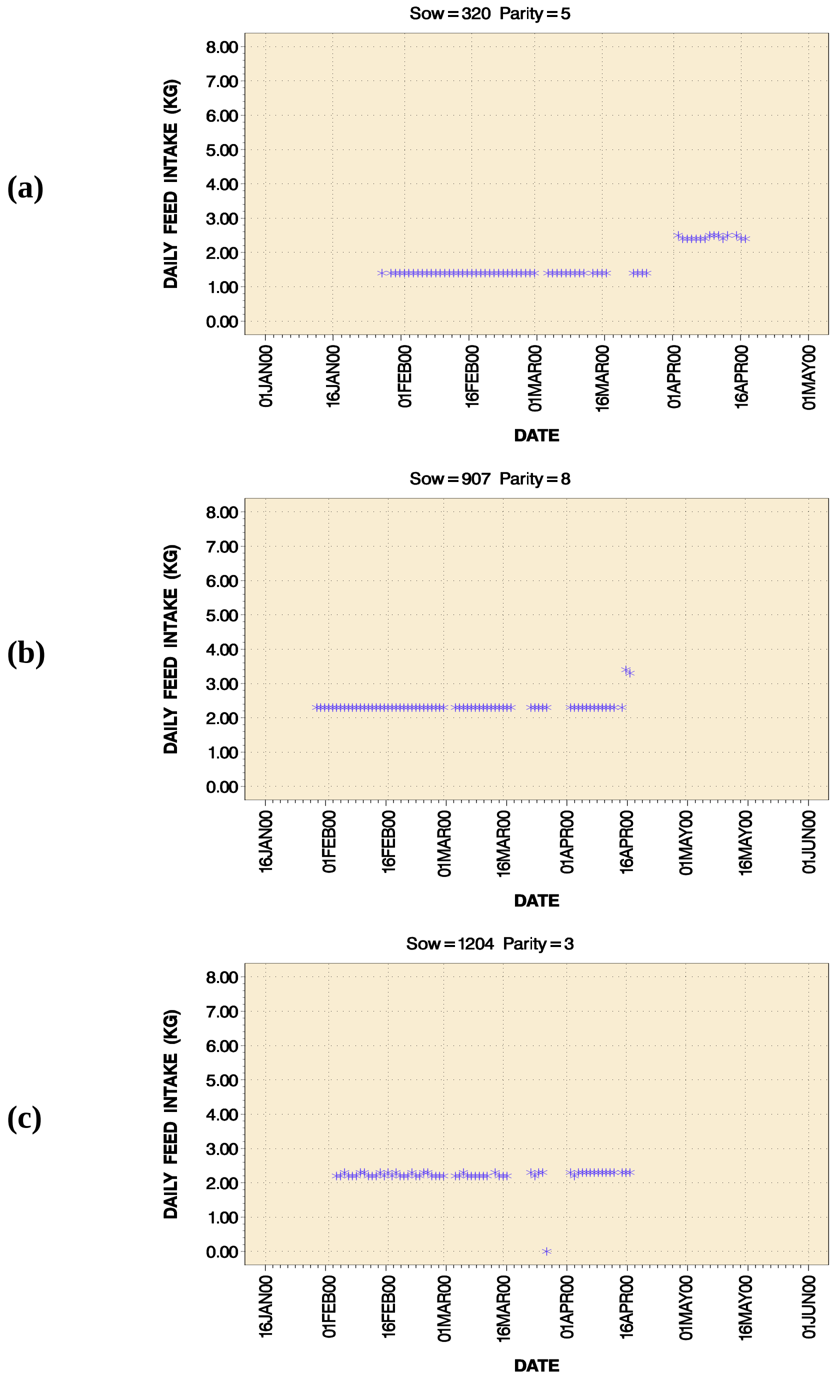


Figure 2.4: Daily feed intake of individual sows defined as amount of feed fed in each feeding cycle. Due to the defined feeding norm, comprising a single increase in feed ration, feed intake seems fairly stable.

must be effected during more than a single feed visit[1], and it seems obvious that large feeding times to some extend must be a result of more than a single feeding visit. Due to this expected correlation, some degree of similarity is expected between feeding time and number of feeding visits. In Figure 2.6 the number of feeding visits in each feeding cycle are shown, and comparing Figure 2.5 and 2.6 also reveals that markedly deviations in feeding time seem to be accompanied by increases in number of feeding visits. Other authors have suggested that it is not always the same sows that eat in a single visit and therefore not the same sows that make out the approximately 80 pct. of sows eating in a single visit Eddison and Roberts (1995).

When the number of feeding visits have been studied the question arises whether some kind of stability or pattern in the total number of visits occur. In Figure 2.7 the total number of visits in each feeding cycle are shown, but no particular patterns or stability seems clear. Extracting feeding visits does not reveal any particular stable patterns in the number of non-feeding visits either, cf. Figure 2.8.

2.3 External influences on eating behaviour

Basically eating behaviour is controlled by the appetite of the individual sow, which again is controlled by a complex correlation between short and long term internal physical, hormonal and neurological factors (Forbes, 1995). However several external factors are in addition known to influence eating behaviour leading to disturbances in the internal short term regulation. In modelling eating behaviour of sows, considerations concerning the influence of external factors on eating behaviour have to be made in order to achieve a reliable handling of these disturbances by the model.

One of the most obvious external factors affecting eating behaviour of sows (and almost every other species) is the overall palatability of the food comprising both smell, taste and structure of the food (Forbes, 1986). Also several other dietary factors i.e. energy and protein contents affects eating behaviour. These factors in fact affects eating behaviour indirectly by triggering the internal physical, hormonal and mechanical regulation mechanisms mentioned above (Forbes, 1995).

However not only external factors related to feed intake affects eating behaviour. Lynch (1989) found that feed intake fell by 12% when air temperature was increased from $21°$C to $27°$C and by 25% when temperature was increased from $16°$C to $27°$C. When sows eat, some of the energy content in feed is transformed to heat due to the digestive processes in the stomach as well as

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[1] assuming that no kind of technical or human disturbance has occurred

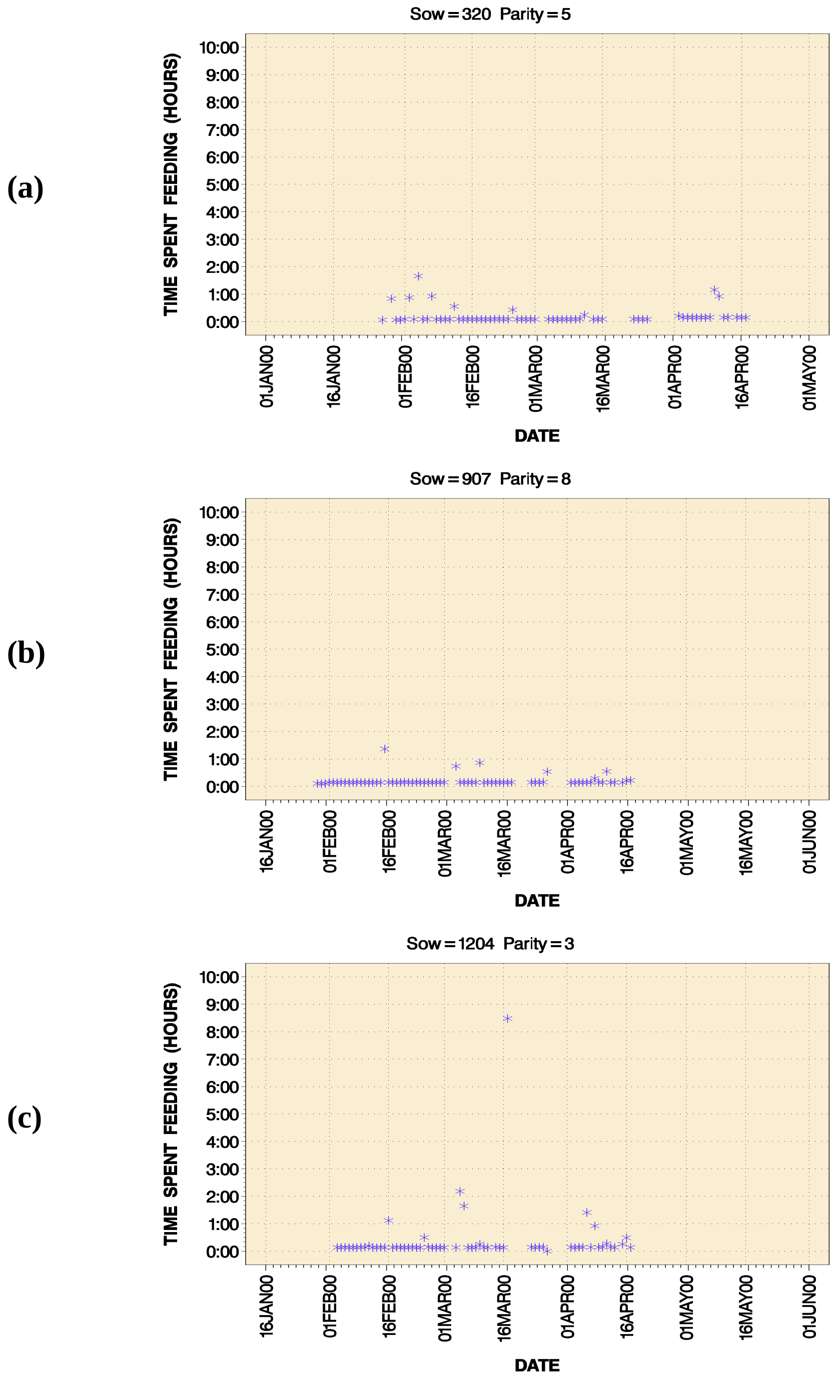

Figure 2.5: Time spent feeding all of a ration in each feeding cycle shows a high degree of stability caused by the predefined feeding speed. Theoretical feed delivery time is 13 minutes including a 4 minutes delay in opening of rear gates.

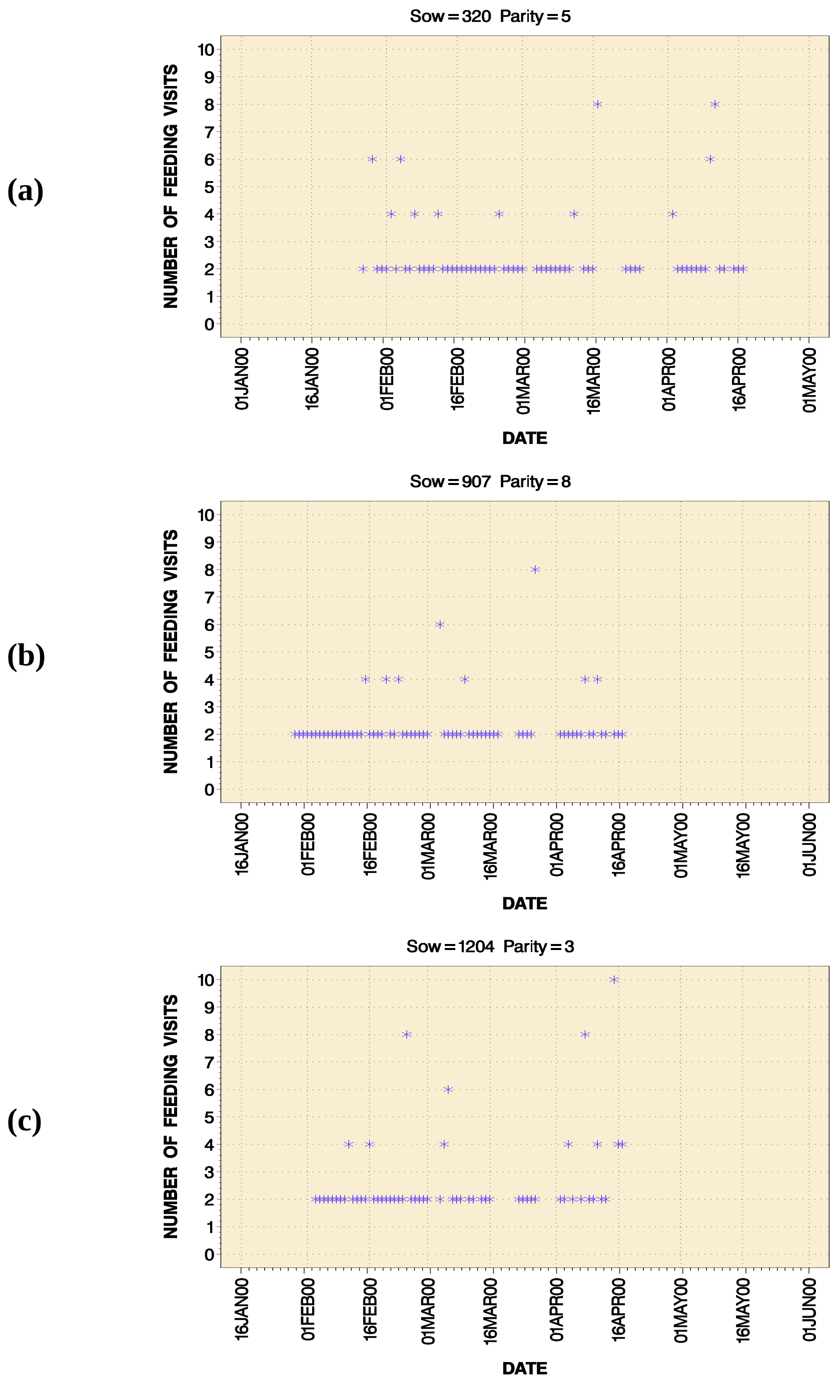

Figure 2.6: Number of feeding visits in each feeding cycle seems fairly stable and shows some kind of similarity to the time spent feeding.

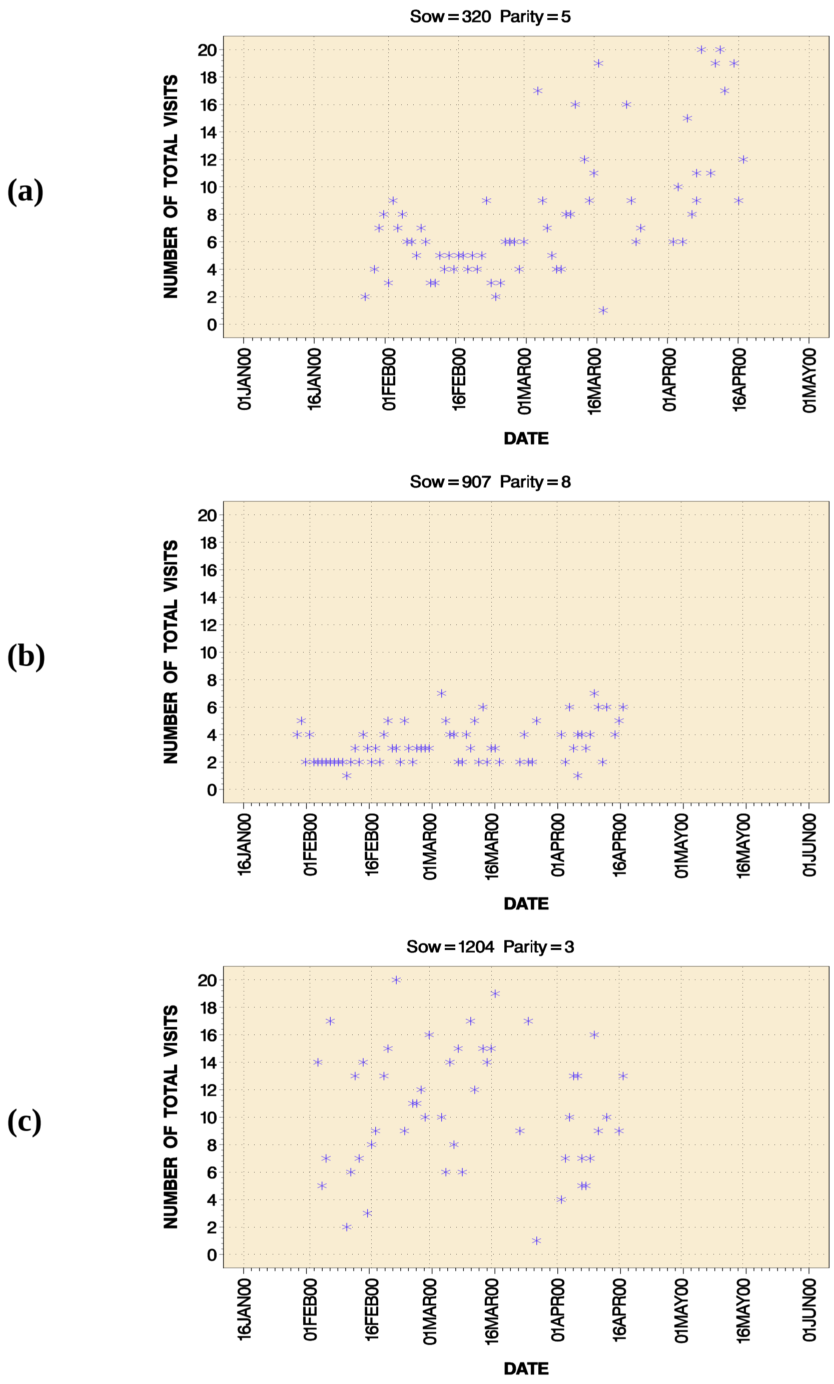

Figure 2.7: Total number of visits in each feeding cycle of individual sows seems not to show any particular pattern or stability, although great variation in the number of visits among sows occur.

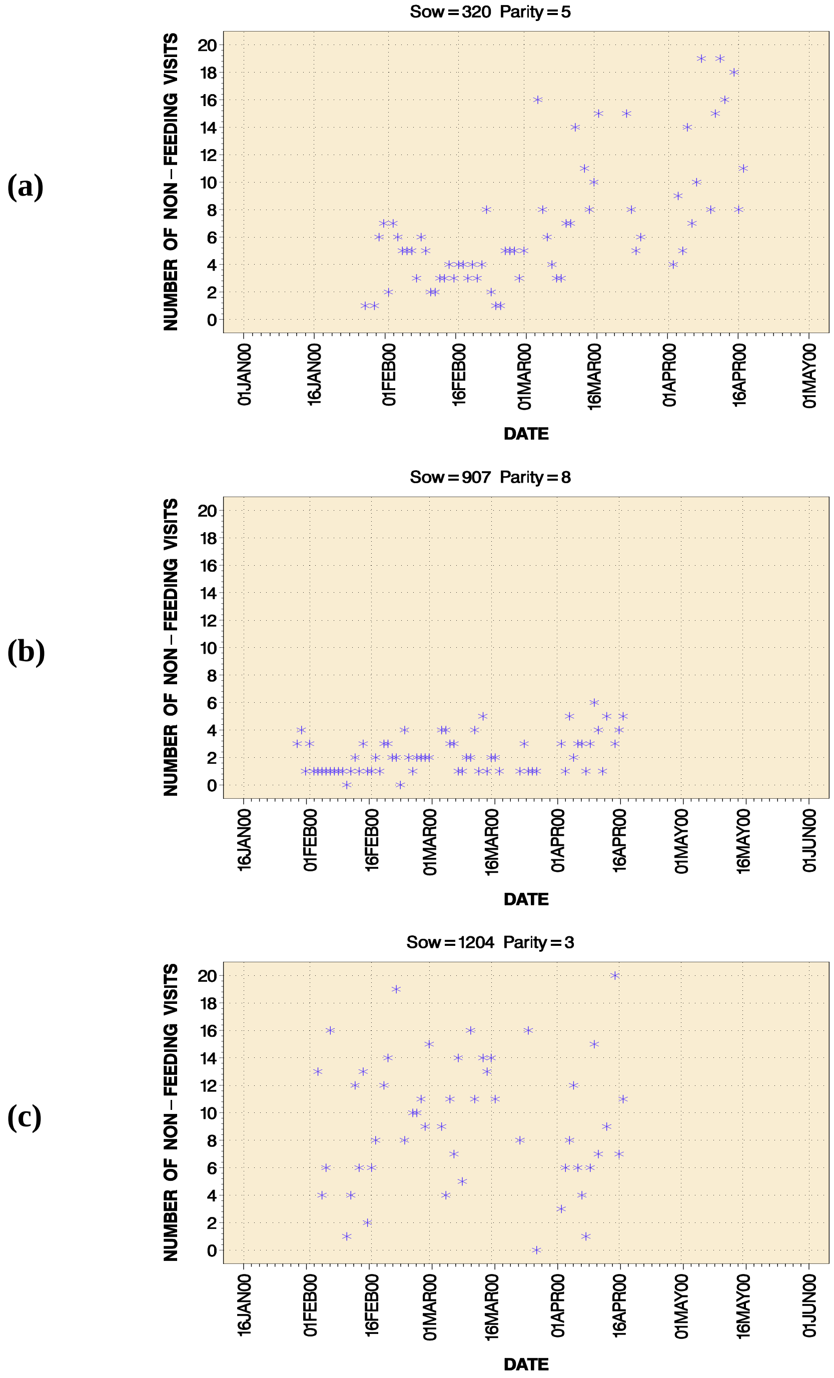

Figure 2.8: In the number of non-feeding visits of individual sows there seems not to be any stability or pattern as for the number of total visits.

the intestines, and body temperature of the sows increases. By overeating the heat loss mechanisms are activated to prevent hyperthermia but if environmental temperature prevents heat loss to be further increased, voluntary feed intake decreases (Forbes, 1995). If in contrary environmental temperature decreases, body reserves will normally be mobilized and eventually feed intake increased in order to prevent undue hypothermia (Forbes, 1995). Apparently the possibilities of heat loss seems to be of major importance in the effect of temperature on eating behaviour. However not only temperature but in particular also relative humidity are important since evaporation is very important as a means of losing heat at high temperatures (Forbes, 1995). It seems obvious when temperature affects eating behaviour that considerable seasonal variation in feed intake might occur. However not only temperature but also daylight have been reported to affect eating behaviour (Forbes, 1995).

In groups of sows a social hierarchy will be established and this social hierarchy in addition affects the eating behaviour of the sows. Hunter et al. (1988) showed that the socially high ranking sows using electronic feed stations primarily were eating in the first half of the feeding cycle, whereas the socially low ranking sows were eating in the last half. In ESF systems the fact that several sows use the same feed station, restricts the sows in their eating behaviour and Brooks and Eddisson (1995) suggested that the sows are only able to eat when the other sows allow it. Further Hunter et al. (1988) and Edwards et al. (1988) have reported that some of the sows perform a number of visits to the feed station although they have already eaten all of their ration, thereby preventing the other sows to eat. The sows most active in performing these non-feeding visits seems to be the socially high ranking sows (Hunter et al., 1988). Supported by the results of Hunter et al. (1988) it seems likely that the socially high ranking sows define their own eating behaviour while the rest of the sows have to adapt their eating behaviour.

Some of the consequences of the sequential feeding is a huge number of aggressions occurring especially in the area in front of the entrance to the feed stations (Hunter et al., 1988; Jensen et al., 2000) and severe injuries on the sows have been reported (Olsson et al., 1992; Svendsen et al., 1992). On this behalf well being of the sows in ESF systems has been questioned, and the factors of importance for success of the ESF system have been reviewed by several authors (Olsson et al., 1992; Brooks and Eddisson, 1995; Jensen et al., 2000). Also the increased level of aggression as well as the injuries of sows must be assumed to be able to affect eating behaviour.

2.4 Concluding comments

The short review of sows' eating behaviour and factors affecting eating behaviour intimate the complex situation in describing eating behaviour of individual sows, and variation might occur both because of interactions among sows and external influences as well as random noise.

Using eating behaviour in automatic oestrus detection some kind of stability is needed in order to be able to identify deviations in eating behaviour and it seems reasonable, that the properties showing most stability are used in oestrus detection. From the Figures 2.2 - 2.8 it seems that the time of first feeding visit, daily feed intake, feeding time and number of feed visit show rather stable patterns and therefore are suitable for modelling.

In the next chapter, two Multi-Process Dynamic Linear Models, used in modelling time of first feeding visit and daily feed intake, are presented. By including two (or more) properties of eating behaviour in modelling, information from both properties may be combined and certainty of identifying deviations increased, due to a more differentiated monitoring of eating behaviour.

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Chapter 3

Multi-Process Dynamic Linear Models used in Oestrus Detection of Group-Housed Sows

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Abstract. In recent years much attention has been paid to animal welfare in Denmark, and the extension of production systems for group-housed sows have emphasized the need for improving management routines concerning oestrus detection. A correlation between oestrus and appetite seems to be supported by decreases in voluntary feed intake during the week of oestrus, and it is investigated if deviations in eating behaviour can be used in oestrus detection in electronic sow feeding systems. Eating behaviour is in this study described by time of first feeding visit and daily feed intake. These two properties of eating behaviour are modeled separately by two Multi-Process Dynamic Linear Models (MP-DLMs), each combined of two Dynamic Linear Models describing a normal and an outlying observation. By modeling of eating behaviour it seems likely that oestrus causes deviations in eating behaviour. However individual variability in eating behaviour seems to cause deviations in eating behaviour not correlated to oestrus, and the applied modelling seems unreliable as a system for oestrus detection.

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3.1 Introduction

The increasing number of production systems for group-housed pregnant sows in electronic sows feeding (ESF) systems in Denmark (Jensen et al., 2000) have emphasized the need for improvement in management routines used in commercial herds, with special interest to the manager's skills and effort in observing changes in animal behaviour.

Daily management of group-housed pregnant sows is to a large extend focused on physical condition, general health and oestrus detection of the individual sows. Although detection of oestrus is of major importance in pig production in order to obtain a punctual mating and reduce the farrowing interval, management concerning oestrus detection in ESF systems has not been paid much attention.

In ESF systems all visits to the feed stations are registered by the feeding computer resulting in data comprising detailed information of individual sows' eating behaviour. Often these data are only used in creating a list of sows who have not been fed all of their daily feed allowance. Additional benefit from the data requires, that they are processed to information or beliefs in the true state of the animals, and used in decision-making by the manager. One way to enhance the management routines in ESF systems is by an increased use of information technologies in recording and processing of data.

In an early study Friend (1971) reported a significant decrease in feed intake during the week of oestrus of 12 gilts and 7 sows fed *Ad libitum*, in a study on the voluntary feed intake on a weekly basis. This was supported by later experiments (Friend, 1973; von Willeke and Metges, 1984) and similar effects of oestrus have been reported in cows (Walton and King, 1986; Trout et al., 1998), ewes and goats (Forbes, 1995). The effects of oestrus on appetite is suggested to be caused by oestrogens inhibiting the hypothalamus and changes metabolic activity of peripheral tissues (Forbes, 1995). By the increased levels of blood oestrogens prior to standing oestrus in pigs (Rojanasthien, 1988; Whittemore, 1993; Forbes, 1995), it seems possible that decreases in feed intake can be used as an indicator of oestrus.

The detailed registrations of individual sows' eating behaviour might give valuable information and form the basis of monitoring and identifying decreases in appetite, thereby increasing benefit of the data as well as management routines. However some form of stability, which might be expressed as a complicated pattern in feeding behaviour, have to occur in order to identify deviations caused by oestrus.

In groups of sows a social hierarchy will be established and this social hierarchy will affect eating behaviour of the sows, suggesting that group housed sows are only able to eat when the other sows allow it. Studying eating behaviour of the individual sows might reveal rather stable patterns in eating behaviour. Hunter et al. (1988), Edwards et al. (1988b) and Bressers et al. (1993) all ranked the sows according to the order in which they visited a feed station. The two former found that, during short periods of 16 and 6 days respectively, sows maintained a consistent feeding order (Edwards et al., 1988b) at least among the socially high ranking sows (Hunter et al., 1988). Bressers et al. (1993) in addition tried to improve daily management by monitoring eating behaviour in order to detect oestrus, but concluded that deviations from the usual feeding order could not be identified due to instability in feeding order during the entire period of pregnancy. However the feeding order was not random, suggesting some form of stability.

Ranking the sows in this way only includes information on a single property of eating behaviour and i.e. information of the amount of feed eaten and number of visits is not included. In addition assumption of a constant feeding order during the entire period of pregnancy can be questioned. Several reports on dynamic groups of pregnant sows using electronic feed stations indicate that introduction of new sows results in high levels of aggression during the first 24 hours following introduction (Bokma and Kersjes, 1988; Hunter et al., 1989; Moore et al., 1993), and it seems reasonable to assume that the frequent introduction of sows or gilts in dynamic groups affects stability of social hierarchy as well as feeding order. Further the study of Bressers et al. (1993) only includes a single property of eating behaviour (feeding order) which in this light seems to be inadequate, whereas combination of information from several properties of eating behaviour might improve monitoring of eating behaviour.

In order to meet the need of enhanced management systems for group housed sows, especially concerning the oestrus detection, it is investigated whether deviations in eating behaviour can be identified and used in detection of oestrus.

In contrast to the studies referred above, eating behaviour is in this study described by two properties of eating behaviour, the time of first feeding visit and the daily feed intake[2], and modeled by use of Multi-Process Dynamic Linear Models (MP-DLMs). The dynamic properties of MP-DLMs enable these models to handle random noise as well as abrupt and gradual changes in eating behaviour, and in each feeding cycle, the probability of deviations in eating behaviour is specified.

The aim of the study is to present the idea of an automatic model based system for detection of oestrus in individual sows in ESF systems by the use of information technology in monitoring eating behaviour and data processing.

3.2 Materials

To obtain information of electronically fed sows' eating behaviour, registration of sows' visits to feed stations were recorded on a commercial farm with 400 sows

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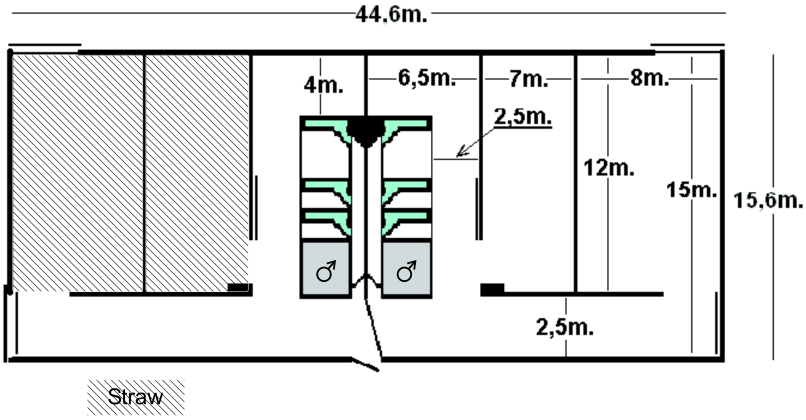
[2] It is assumed that daily feed intake equals the amount of feed fed, knowing that this is not necessarily the truth.

and approximately 85 pct. of the sows farrowing after first mating. The gestation house comprised two pens for dynamic groups of approximately 150 sows using electronic NEDAP feed stations operated by ear tag responders. The feed stations had forward exits leading the sows away from the feeding area.

Newly mated sows were moved to gestation once a week, 3-5 days after mating and split up into the two groups. Newly mated gilts were moved to a separate feed station approximately 4 weeks after mating where they were trained for at least 2 weeks in order to become familiar with feed stations before entering one of the groups in gestation house. All sows and gilts stayed in gestation until approximately one week before expected farrowing, where sows were moved to individual farrowing crates. During pregnancy sows were fed 2.1-2.7 FEs (∼16-21 MJ NE) per day according to the feed standard of pregnant sows recommended by The National Committee for Pig Production, The Danish Bacon and Meat Council. Feed was increased once, 12 weeks after mating. The average portion size was 100 g with a delivery time between two consecutive portions of 22 seconds. This results in a theoretical feeding time of approximately 13 minutes, including a 250 seconds delay from last portion delivery until opening of rear gates, if all of a 2.6 kg ration were eaten in a single visit.

The pen was designed with concrete floor in the feeding and dunging areas, whereas lying area was with deep litter of straw, cf. Figure 3.1. Approximately 1 kg of straw per sow per day were added once daily. Within each of the groups a boar pen was located enabling the sow to see and smell the boar.

Figure 3.1: Sketch of the gestation house, comprising two pens of approximately 150 sows in each. The pens were designed with concrete in dunging and feeding areas and straw in lying areas. In Period 1 and 2 the sows in group 2 had only access to two feed stations.



The feeding cycle started at approximately 16:30. Visits of the sows to the feed station were registered automatically and saved once a day on a personal computer connected to the feeding computer by a special logger unit. Every single visit was registered by date, time, responder-ID, feed station-ID, amount of daily feed allowance left in the actual feeding cycle and amount of daily feed allowance fed in the actual feeding cycle.

Data recording has been performed successfully in three consecutive periods of 69, 73 and 75 days respectively. In the two first periods the sows were split up according to their identification number with odd (group 1) and even (group 2) numbered sows in each of the two pens. Sows in group 1 had access to 3 feed stations whereas group 2 only had access to two feed stations. In the third period sows were split up according to their parity with gilts and first parity sows in group 1 and older sows in group 2. Additionally feed stations were turned off at 14:00 in period 3 in order to prevent sows accessing feed stations until a new feed cycle was started.

3.3 Methods

The studies made by Hunter et al. (1988) showed that the feeding order of group housed sows in stable groups using an electronic feed station were affected by the social rank of sows. In accordance to this it seems reasonable to assume that the eating behaviour of electronically fed sows is fairly stable, although stability in dynamic groups might be less stable according to the frequent introduction of new sows.

In animal husbandry Dynamic Linear Models have been shown useful in monitoring systems by modelling growth in poultry production (Roush et al., 1992), lactation curve in dairy production (Goodall and Sprevak, 1985) as well as eating (Toft and Madsen, 1999) and drinking behaviour (Madsen, 1999) in pig production. However DLMs only adapts gradually to abrupt changes such as growth rate changes and level shifts. By combining several DLMs, each describing a different development in time series, a suitable modelling of time series can be achieved, including both gradual and abrupt changes (West and Harrison, 1997; Thysen, 1993). Such combination of several DLMs is called multi-process dynamic linear models (MP-DLMs). The combining of dynamic linear models is effected by using discrete probability mixtures. At each time step, each of the DLMs in the multi-process model is specified by a probability of how likely it is, that the observations at each time step are described by each of the DLMs. In this study eating behaviour is modeled for each individual sow and the model is updated in accordance to the individual sow's eating behaviour, enabling the model to adapt individually to the individual sows, and thereby increase flexibility of the model.

In animal husbandry Multi-Process Dynamic Linear Models have been used in modelling daily milk production (Thysen, 1992) and bulk tank somatic cell counts (Thysen, 1993).

3.3.1 The Multi-Process Dynamic Linear Model

In the present study eating behaviour is described by the time of first feeding visit and the daily feed intake, due to the stability of these properties, identified by plot of raw data. To each of the properties a Multi-Process Dynamic Linear Model is applied, each consisting of two Dynamic Linear Models (DLMs), describing a normal observation and an outlying observation, respectively.

The applied Dynamic Linear Models are widely used in modelling time series that behave generally according to a second-order polynomial (West and Harrison, 1997), basically asuming a local constant growth rate. All bold characters in the following assign vectors or matrices. The DLMs are characterized by a set of quadruples $\{\mathbf{F}, \mathbf{G}, V(k)V, \mathbf{W_t}\}$ for each time t, where

- $\mathbf{F} = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$ is a known, constant design matrix
- $\mathbf{G} = \begin{pmatrix} 1 & 1 \\ 0 & 1 \end{pmatrix}$ is a known, constant evolution matrix
- $V(k)$ is an observation variance factor relating to the k'th model, where $k = \{1, 2\}$ corresponds to the normal and outlier models respectively
- V is an unknown, constant scalar observation variance
- $\mathbf{W_t}$ is a known (2×2) evolution variance matrix.

At each time step t, the dynamic linear models are defined by the following equations:

Observation equation:

$$Y_t = \mathbf{F}'\theta_\mathbf{t} + \nu_t \qquad \nu_t \sim N[0, V] \tag{3.1}$$

System equation:

$$\theta_\mathbf{t} = \mathbf{G}\theta_\mathbf{t-1} + \omega_\mathbf{t} \qquad \omega_\mathbf{t} \sim T_{n_{t-1}}[0, \mathbf{W_t}] \tag{3.2}$$

where Y_t is the observation at time t and $\theta_\mathbf{t} = \begin{pmatrix} \mu_t \\ \beta_t \end{pmatrix}$ is a state vector consisting of the level μ_t and the growth parameter β_t. The error terms ν_t and ω_t are assumed normally distributed, independent, mutually independent and independent of the initial information $(\theta_\mathbf{0}|D_0) \sim N[\mathbf{m_0}, \mathbf{C_0}]$ (West and Harrison, 1997). Equation (3.1) and (3.2) implies that the observation at time t is expected to be given by the level at time $t-1$, μ_{t-1} added a growth factor β_t as well as random noise terms ν_t

and $\omega_{t,1}$, whereas the growth factor β_t is given by the growth factor at time $t-1$, β_{t-1} added the random noise term $\omega_{t,2}$.

A characteristic of the DLMs is that existing information about the system is represented and sufficiently summarized by the posterior distribution of the current state vector (West and Harrison, 1997),

$$(\boldsymbol{\theta_t}|D_t) \sim N[\mathbf{m_t}, \mathbf{C_t}] \tag{3.3}$$

where D_t is the available information at time t defined by all prior observations and the initial prior information D_0:

$$D_t = \{Y_t, Y_{t-1}, \ldots, Y_1, D_0\}$$

In updating of DLMs each new observation Y_{t+1} is included in the available information D_t, which is updated to D_{t+1}. Inclusion of the last observation is expressed by an adaptive coefficient $\mathbf{A_{t+1}}$ that weights the importance of the observation Y_{t+1} relative to the estimated level $\mathbf{m_t}$. If the observation variance V is relatively large compared to evolution variance $\mathbf{W_t}$, the adaptive coefficient becomes small allowing the model to be almost unaffected by the observation. Conversely the adaptive coefficient becomes large if evolution variance is large compared to observation variance and the model adapts almost immediately to the new observation (West and Harrison, 1997).

The observation variance is often unknown and large relative to the system variance $\mathbf{W_t}$, thereby being a major source of uncertainty in forecasting. By assuming observational variance constant, $V_t = V$ for all t, V may be expressed by the precision parameter $\phi = V^{-1}$ with $E[\phi|D_0] = S_0^{-1}$, where S_0 is a prior point estimate of V (West and Harrison, 1997). As ϕ follows a Gamma distribution with parameters n_t and d_t, where $n_t = n_{t-1} + 1$ $n_0 = 0$ and $d_t = n_t S_t$, it can be shown that $\boldsymbol{\theta_t}$ follows a multivariate T distribution with n_t degrees of freedom, instead of being normally distributed (see West and Harrison, 1997, chap. 17.3). Hence the system information in Equation (3.3) is replaced by

$$(\boldsymbol{\theta_t}|D_t) \sim T_{n_t}[\mathbf{m_t}, \mathbf{C_t}] \tag{3.4}$$

and

$$(\phi|D_t) \sim G\left[\frac{n_t}{2}, \frac{d_t}{2}\right]. \tag{3.5}$$

In estimating evolution variances $\mathbf{W_t}$, a discount factor technique is used, where $\mathbf{W_t}$ is estimated as a proportion of the overall posterior uncertainty of the system $\mathbf{C_{t-1}}$. Given the usual posterior distribution $(\boldsymbol{\theta_{t-1}}|D_{t-1}) \sim T_{n_{t-1}}[\mathbf{m_{t-1}}, \mathbf{C_{t-1}}]$ at time $t-1$, write

$$\mathbf{C_{t-1}} = \begin{pmatrix} C_{t-1,\mu} & C_{t-1,\mu\beta} \\ C_{t-1,\mu\beta} & C_{t-1,\beta} \end{pmatrix}$$

Separate discount factors for the level and growth factor are denoted δ_μ and δ_β respectively and the evolution variance matrix is defined by

$$\mathbf{W_t} = \begin{pmatrix} W_{t,\mu} + W_{t,\beta} & W_{t,\beta} \\ W_{t,\beta} & W_{t,\beta} \end{pmatrix} \tag{3.6}$$

where $W_{t,\mu} = C_{t-1,\mu}(\delta_\mu^{-1} - 1)$ and $W_{t,\beta} = C_{t-1,\beta}(\delta_\beta^{-1} - 1)$. The discount factor technique is widely used in DLMs since it is difficult to estimate the evolution variance. In updating of evolution variance separate discounts factor are used in updating level and growth factor parameters (West and Harrison, 1997).

As mentioned above each of the multi-process models is combined of two DLMs describing a normal and an outlying observation. The outlier DLMs are characterized by a relatively large observational variances compared to the normal DLMs, resulting in small adaptive coefficients, thereby practically ignoring the observation. Large observation variance is achieved by multiplying the variance estimate S_t by an observation variance factor $V(k)$, where $V(k) = 1$ applies to the normal case of $V = S_t$. Below characteristics of the normal and outlier models are summarized.

Time of first feeding visit

Normal model with observation variance factor $V(k) = 1$ and discount factors $\delta(\mu) = 0.95$ and $\delta(\beta) = 0.8$.

Outlier model with observation variance factor $V(k) = 100$ and discount factor $\delta(\mu) = 0.95$ and $\delta(\beta) = 0.8$.

Daily feed intake

Normal model with observation variance factor $V(k) = 1$ and discount factors $\delta(\mu) = 0.95$ and $\delta(\beta) = 0.8$.

Outlier model with observation variance factor $V(k) = 1000000$ and discount factor $\delta(\mu) = 0.95$ and $\delta(\beta) = 0.8$.

In accordance with the theory of the MP-DLM (West and Harrison, 1997, chap. 12), observation variance factors of the outlier models are set to ensure that the observation variances of th eoutlier models becomes be greater than observation variances of the normal models. The observation variance factor for the outlier model in modelling daily feed intake is set relatively large to cope with small ($\sim 10^{-7}$) variance estimates caused by the restrictive feeding of sows. The discount factors of the growth factor $\delta_{t,\beta}$ are set to be less than $\delta_{t,\mu}$ in order for the model more rapidly to adapt to growth rate changes.

Prior probabilities

To calculate the probabilities of model combinations, fixed prior probabilities for each of the models must be specified within each of Multi-Process models. Since introduction to gestation occurs after mating, the mating dates of the individual sows are known, and this information might be useful in identifying unsuccessful matings. By defining the day of mating as day 0 in the oestrus cycle, the next oestrus is expected to occur approximately around day 21, if mating has been unsuccessful. The apparent correlation between increases in blood oestrogen level prior to standing oestrus and decreases in appetite, makes the days just prior to day 21 after mating of special interest. In this study two 5 days sensitive periods from day 18 to day 22 and from day 39 to day 43, respectively, are applied to the models, by increasing prior probabilities. Defining only two sensitive periods implicitly indicate, that sensitivity to deviations in eating behaviour are increased only during the first two oestrus cycles after mating. This is due to a decreased response to increases in oestrogen level and a shortening of pro-oestrus period with increasing number of successive oestrus' in gilts, possibly explained by decreased susceptibility of vulvar hormonal receptor mechanism (Andersson et al., 1984). The unequal distribution of the sensitive periods around day 21 and 42 after mating is caused by expectation of eating behaviour to deviate prior to standing oestrus in accordance to the occurrence of increases in levels of oestrogens (Rojanasthien, 1988; Whittemore, 1993; Forbes, 1995).

Oestrus however not only occurs inside the defined sensitive period, and prior probabilities of oestrus occurring outside the periods must in addition be specified. These prior probabilities can be regarded as a kind of background probability of oestrus to occur, but are however not easy to estimate since factors as the manager's skills in identifying and register oestrus as well as boar's mating or the insemination are of importance. Also unnatural hormonal changes in the sow affects the occurrence of oestrus outside the sensitive periods. The 15 pct. unsuccessful matings in the commercial farm is in the present study assumed to be distributed by 80 pct. of the sows returning to service regularly within the 5 days sensitive period and 20 returning to service irregularly in the remaining 16 days.

If N_O assigns the number of outliers in each of the two monitored time series with a single observation of the individual sows in each feed cycle, it is expected that $N_O \sim B(n_O, p_O)$, where n_O is the number of feed cycles in the period and p_O is the probability that an outlying observation occurs in a single feed cycle.

With an assumed probability of 0.12 that an unsuccessfully mated sow returns to service regularly (5 days period), p_O is given by

$$P(N_O \leq 0) = \binom{5}{0} p_O^0 (1 - p_O)^5 = 0.88 \Leftrightarrow p_O = 1 - \sqrt[5]{0.88} = 0.025,$$

whereas P_O of an unsuccessfully mated sow returning to service irregularly (16 days period) is given by:

$$P(N_O \leq 0) = \binom{16}{0} p_O^0 (1 - p_O)^{16} = 0.97 \Leftrightarrow$$

$$p_O = 1 - \sqrt[16]{0.97} = 0.002.$$

Given the probabilities of the outlier models, normal model probabilities have been set to values ensuring that the prior probabilities sum to unity. The prior probabilities are summarized in Table 3.1.

Table 3.1: Prior probabilities used in modelling time of first visit and daily feed intake by two multi-process dynamic linear models.

	Normal period	Sensitive period
π_N	0.998	0.975
π_O	0.002	0.025

3.3.2 Updating and development of the MP-DLMs

To be able to start the updating of the MP-DLMs, initial prior information D_0 has been estimated for each time series of the individual sows, by the reference analysis described by West and Harrison (1997, chap. 4.10). The DLMs consists of three parameters, the level μ_t, the growth factor β_t and the unknown constant observation variance V. To gain proper posterior joint distributions conditional on the initial prior information $(\theta_\mathbf{0}|D_0)$, the least number of observations that will suffice equals the number of unknown parameters, one observation for each parameter. During the reference analysis it is assumed that $\mathbf{W_t} = 0$, which for practical purposes is sufficient, since non-zero matrices would allow for changes that can not be estimated before an estimate of W_t exists and nothing is lost setting $\mathbf{W_t} = 0$ (West and Harrison, 1997).

Updating of the MP-DLMs is performed using the Kalman Filter as described by West and Harrison (1997, chap. 12), that sequentially updates posterior distributions posterior distributions at time $t - 1$ to posterior distributions at time t, in consistence with the assumptions of independency.

Modelling at time $t > 1$ creates new model combinations since modelling at time t is performed within each of the models at time $t - 1$. With the MP-DLMs consisting of two DLMs the total number of model combinations at time $t = n$ equals 2^n. However model combinations back in time becomes of less and less importance and to prevent this rapid increase, model combinations prior to a given time are collapsed (West and Harrison, 1997). In this study, model combinations identical at time t and $t - 1$ but different at time $t - 2$ are collapsed. With two

DLMs in the MP-DLMs the number of model combinations is reduced from 8 to 4 by the model collapse. Within each of these 4 collapsed model combinations, the two possible DLMs are applied in the next time step resulting in 8 new model combinations, which then is collapsed etc.

In the following the sequential updating equations of the Kalman Filter as well as the collapsing procedure are summarized (Thysen, 1993; West and Harrison, 1997). Model combinations is stated by the notation $(ijk) = (M_{t-2}, M_{t-1}, M_t)$, where M_t assigns the model (Normal or Outlier) at time t. Collapsed model combination at time t is stated by the notation $(ij) = (M_{t-2}, M_{t-1})$.

Remember that information of the system at time $t-1$ is given by a T distribution with n_{t-1} degrees of freedom, mean $\mathbf{m_{t-1}}(\mathbf{ijk})$ and variance $\mathbf{C_{t-1}}(\mathbf{ijk})$ conditional on all previous information D_{t-1}, see Equation (3.4). The first step in updating of the MP-DLMs is formation of the prior distribution of $\theta_\mathbf{t}$ conditional on D_{t-1}, where the expected prior level $\mathbf{a_t}(\mathbf{ijk})$ is given by the posterior collapsed level $\mathbf{m_{t-1}}(\mathbf{ij})$ increased by the growth factor, and the expected prior variance $\mathbf{R_t}(\mathbf{ijk})$ is given by the collapsed posterior variance $\mathbf{C_{t-1}}(\mathbf{ijk})$ added the evolution variance of the k'th model $\mathbf{W_t}(\mathbf{k})$, the latter estimated as in Equation (3.6).

$$\mathbf{a_t}(\mathbf{ijk}) = \mathbf{G}\mathbf{m_{t-1}}(\mathbf{ij}) \tag{3.7}$$

$$\mathbf{R_t}(\mathbf{ijk}) = \mathbf{G}\mathbf{C_{t-1}}(\mathbf{ij})\mathbf{G}' + \mathbf{W_t}(\mathbf{k}), \tag{3.8}$$

The second step is formation of the 1-step forecast of the observation at time t, and is determined by the prior mean and variance added the observation variance. Since observation variance is assumed to be normally distributed with zero mean, the 1-step forecast mean of the observation at time t is given by the expected level of the prior distribution (3.7)

$$f_t(ijk) = \mathbf{F}'\mathbf{a_t}(\mathbf{ijk}). \tag{3.9}$$

whereas the 1-step forecast variance of the observation at time t is given by the prior variance (3.8) added the estimated observation variance for the model combination (ijk)

$$Q_t(ijk) = \mathbf{F}'\mathbf{R_t}(\mathbf{ijk})\mathbf{F} + S_{t-1}(ij)V(k). \tag{3.10}$$

The third step in updating the MP-DLMs consist in updating the posterior distribution of $\theta_\mathbf{t}$ when the observation Y_t is known. By this step an additional observation is applied to the time series and information increased form D_{t-1} to D_t. In order to update the posterior distribution, the forecast error and the adaptive coefficient is determined as well as parameters used in estimating observation variance are updated.

- Forecast error

$$e_t(ijk) = Y_t - f_t(ijk) \tag{3.11}$$

- Adaptive coefficient

$$\mathbf{A_t}(\mathbf{ijk}) = \frac{\mathbf{R_t}(\mathbf{ijk})\mathbf{F}}{Q_t(ijk)} \tag{3.12}$$

- Degrees of freedom

$$n_t = n_{t-1} + 1 \tag{3.13}$$

- Gamma distribution scale parameter

$$d_t(ijk) = d_{t-1}(ij) + \frac{S_{t-1}(ij)e_t(ijk)^2}{Q_t(ijk)} \tag{3.14}$$

- Observation variance estimate

$$S_t(ijk) = \frac{d_t(ijk)}{n_t} \tag{3.15}$$

The forecast error expresses the difference between the expected level and the actual observation, and the adaptive coefficient expresses the weight of the last observation in updating the posterior distribution. The observation variance estimate $S_t(ijk)$ is determined by $d_t(ijk)$ and n_t, where $d_t(ijk)$ is defined by $d_{t-1}(ij)$ corrected for the concordance between the last observation and the model. If model suits the observation well, the 1-step forecast error becomes smaller resulting in less correction of $d_{t-1}(ij)$.

Now the posterior distribution of θ_t is estimated by adding the product of the adaptive coefficient and the forecast error to the prior estimate of the level, and reduce the prior variance by $\mathbf{A_t}\mathbf{A_t'}Q_t$, according to Bayes' theorem (West and Harrison, 1997).

$$\mathbf{m_t}(\mathbf{ijk}) = \mathbf{a_t}(\mathbf{ijk}) + \mathbf{A_t}(\mathbf{ijk})e_t(ijk) \tag{3.16}$$

$$\mathbf{C_t}(\mathbf{ijk}) = \frac{S_t(ijk)}{S_{t-1}(ij)}(\mathbf{R_t}(\mathbf{ijk}) - \mathbf{A_t}(\mathbf{ijk})\mathbf{A_t}(\mathbf{ijk})'Q_t(ijk)) \tag{3.17}$$

Hereby the posterior mean at time $t-1$ is corrected by the last observationt's weighted influence, ending the updating of the posterior distribution at time $t-1$ to posterior distribution at time t.

In order to weight each of the model combinations the probabilities of the model combinations is determined by

$$p_t(ijk) = \frac{c_t\pi(k)p_{t-1}(ij)}{\sqrt{Q_t(ijk)}[n_{t-1} + e_t(ijk)^2/Q_t(ijk)]^{n_t/2}} \tag{3.18}$$

where c_t is a constant of normalization such that

$$\sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{2} p_t(ijk) = 1$$

Determination of these probabilities makes it possible to determine a weighted mean of the posterior means and variances by

$$\mathbf{m_t} = \sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{2} \mathbf{m_t}(\mathbf{ijk}) p_t(ijk) \tag{3.19}$$

and

$$\mathbf{C_t} = \sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{2} [\mathbf{C_t}(\mathbf{ijk}) + (\mathbf{m_t}(\mathbf{jk}) - \mathbf{m_t}(\mathbf{ijk}))^2] p_t(ijk) \tag{3.20}$$

In order to prevent the rapidly increase in total number of model combinations, model combinations at time $t-2$ are collapsed before updating of the MP-DLMs is proceeded. This is done by weighting the model combinations and summing model combinations similar at time t and $t-1$ but different at time $t-2$.

$$p_t(jk) = \sum_{i=1}^{2} p_t(ijk) \tag{3.21}$$

$$S_t(jk) = [\sum_{i=1}^{2} \frac{p_t(ijk)}{S_t(ijk) p_t(jk)}]^{-1} \tag{3.22}$$

$$d_t(jk) = n_t S_t(jk) \tag{3.23}$$

$$\mathbf{m_t}(\mathbf{jk}) = \sum_{i=1}^{2} \mathbf{m_t}(\mathbf{ijk}) p_t^*(ijk) \tag{3.24}$$

$$\mathbf{C_t}(\mathbf{jk}) = \sum_{i=1}^{2} [\mathbf{C_t}(\mathbf{ijk}) + (\mathbf{m_t}(\mathbf{jk}) - \mathbf{m_t}(\mathbf{ijk}))^2] p_t^*(ijk) \tag{3.25}$$

where $p_t^*(ijk) = \frac{S_t(jk) p_t(ijk)}{S_t(ijk) p_t(jk)}$ and sum to unity, $\sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{2} p_t^*(ijk) = 1$.

By this last step in updating of the MP-DLMs, updating of the next step and inclusion of the observation Y_{t+1} can be started.

Back step filtering

The accuracy of identifying outlying observations is of great importance, in order to increase certainty by which deviations in eating behaviour are identified. At the time of an outlying observation it is impossible to identify the observation as either an outlier or the beginning of a level shift. In practice the differing of an outlier from a level shift is first possible at the time of the next observation $(t+1)$ or at time $t+2$ if two consecutive outliers can be expected.

To handle this situation a back step filtering or smoothing is performed. The 1-step back filtering specify the model probability mixture at time t conditional on D_t and Y_{t+1} whereas the 2-step back filtering specify the model probability mixture at time t conditional on D_t, Y_{t+1} and Y_{t+2} (West and Harrison, 1997). The smoothing process increases the certainty of which dynamic linear model best describes a given observation, but delays the information, in that an outlying observation at time t is not identified before time $t+1$ or $t+2$ respectively. Equations 3.26 - 3.28 below details the back step filtering of probabilities.

- Smoothed model probabilities

$$p(k) = \sum_{i=1}^{2} \sum_{j=1}^{2} p_t(ijk) \tag{3.26}$$

$$p(j) = \sum_{i=1}^{2} \sum_{k=1}^{2} p_t(ijk) \tag{3.27}$$

$$p(i) = \sum_{j=1}^{2} \sum_{k=1}^{2} p_t(ijk) \tag{3.28}$$

Missing observations

When sows are not visiting the feed stations or data recording breaks down, the result is missing observations. In these situations increased uncertainty exist about the future, and it becomes impossible to update the model from posterior at time $t-1$ to posterior at time t by the normal updating procedure.

If the observation Y_t is missing, evolving to time t applies no additional information to the model. The information at time t is just $D_t = D_{t-1}$ and the posterior distribution at time t equals the prior distribution at time t (West and Harrison, 1997),

$$\mathbf{m_t} = \mathbf{a_t} \quad and \quad \mathbf{C_t} = \mathbf{R_t}, \tag{3.29}$$

reflecting the increased uncertainty by the prior variance estimate. In addition parameters used in estimation of observation variance V are not updated,

$$n_t = n_{t-1}, \quad d_t = d_{t-1} \quad and \quad S_t = S_{t-1}. \tag{3.30}$$

The updating of evolution variance $\mathbf{W_t}$ using discount factors is also disturbed by missing observations. Evolving to time t, $\mathbf{W_t}$ is determined as a part of the variance $\mathbf{C_{t-1}}$ provided that Y_{t-1} is observed. If Y_t is missing, evolution variance $\mathbf{W_{t+1}}$ is based on the most recently defined evolution variance $\mathbf{W_{t+1}} = \mathbf{W_t}$ when an observation was made (West and Harrison, 1997).

Normal updating of probabilities $p_t(ijk)$ is also impossible if an observation is missing and adjustments have to be made. Since nothing is known about the observation (except that it is missing), the best information might be given by the specified prior probabilities, that state the back ground probability of an observation to be normal or outlying independent of previous observations. In updating of probabilities, the missing observation is assumed to equal the model forecast enabling a normal updating of $Q_t(ijk)$ and forecast errors $e_t(ijk)$, with the missing observation weighted in accordance to the prior probabilities.

In modelling daily feed intake a different approach is assumed in that a missing observation might be caused by sows not eating. By assuming the missing observation to equal a daily feed intake of 0, no information is lost and it becomes possible to to update the model following the normal procedure. In identifying oestrus by use of eating behaviour it is important to utilize this information, and in general herd management as well information of sows not eating all of their ration is of interest.

The primary concern in updating of the MP-DLM in this way regards the updating of variance estimates, since the extreme observation values applies additional variance to the system. In situations where the missing observation truly is caused by sows not eating, the additional variance is acceptabel. However if missing observations are caused by break down of data recording the additional variance is undesirable and might decrease sensitivity in identifying deviations.

3.3.3 Intervention effects applied to the MP-DLMs

With each of the Multi-Process models consisting of only two models, describing a normal and an outlier observation respectively, the ability of the MP-DLMs to handle abrupt changes or level shifts are reduced. In time series of daily feed intake such level shifts are known to occur since daily feed allowance is increased during pregnancy following a predefined pattern. Instead of applying an additional model describing a level shift to the MP-DLMs, these level shifts are handled by intervention effects. Due to the predefined feeding norm, increases in feed rations are regarded as known information, which also in the case of a manual increase of feed ration by the manager might be valid, since a manual increase of daily feed allowance is known and the level of daily feed intake is expected to increase.

Inclusion of such intervention effects are described by West and Harrison (1997, chap. 11.2). The intervention is effected by adding an additionally noise term ξ_t to the system equation (3.2), where intervention information is given by $I_t = \{\mathbf{h_t}, \mathbf{H_t}\}$ with $\xi_t \sim N[\mathbf{h_t}, \mathbf{H_t}]$ and prior information on the system given by

$$(\theta_\mathbf{t}|I_t, D_{t-1}) \sim T_{n_{t-1}}[\mathbf{a_t^*(ijk)}, \mathbf{R_t^*(ijk)}],$$

$$\mathbf{a_t^*(ijk)} = \mathbf{a_t(ijk)} + \mathbf{h_t} \qquad \mathbf{R_t^*(ijk)} = \mathbf{R_t(ijk)} + \mathbf{H_t}.$$

This arbitrary intervention does however not provide a coherent joint distribution for $\theta_\mathbf{t}$ and $\theta_\mathbf{t-1}$ conditional on both D_{t-1} *and* I_t when filtering and smoothing the time series. In order to provide a coherent joint distribution intervention effects have to be expressed in a form consistent with the DLMs. By specifying $\mathbf{a_t^*(ijk)}$ and $\mathbf{R_t^*(ijk)}$ the system equation (3.2) can be amended to

$$\theta_\mathbf{t}(\mathbf{ijk}) = \mathbf{G_t^*(ijk)}\theta_\mathbf{t-1}(\mathbf{ijk}) + \omega_\mathbf{t}^*(\mathbf{ijk}), \tag{3.31}$$

$$\omega_\mathbf{t}^*(\mathbf{ijk}) \sim T_{n_t}[\mathbf{h_t(ijk)}, \mathbf{W_t^*(ijk)}],$$

where

$$\mathbf{G_t^*(ijk)} = \mathbf{K_t(ijk)G}$$

$$\omega_\mathbf{t}^*(\mathbf{ijk}) = \mathbf{K_t(ijk)}\omega_\mathbf{t}(\mathbf{ijk}) + \mathbf{h_t(ijk)}$$

$$\mathbf{W_t^*(ijk)} = \mathbf{K_t(ijk)W_t(ijk)K_t(ijk)'}$$

$$\mathbf{K_t(ijk)} = \mathbf{U_t(ijk)Z_t^{-1}(ijk)}$$

$$\mathbf{h_t(ijk)} = \mathbf{a_t^*(ijk)} - \mathbf{K_t(ijk)a_t(ijk)}$$

and $\mathbf{U_t(ijk)}$ and $\mathbf{Z_t(ijk)}$ are the unique upper-triangular, non-singular square root matrices of $\mathbf{R_t^*(ijk)}$ and $\mathbf{R_t(ijk)}$ respectively.

This means that on the days of known level shifts in daily feed intake system equation (3.2) is amended to (3.31) thereby including the intervention effect in a way consistent with the theory of dynamic linear models. By the predefined feeding norm increases in daily feed allowance occurs on day 85 after mating and feed is normally increased by 1000 g. However manually adjustments may have been made in accordance to the condition of the sows as well as uncertainty exists whether the sows increase daily feed intake immediately. To handle this increased uncertainty of the future, evolution variance is increased simultaneous with the change in level by a factor 2. In summary intervention effects are given by

$$\mathbf{a_t^*(ijk)} = \mathbf{a_t(ijk)} + \begin{pmatrix} 1000 \\ 0 \end{pmatrix} \tag{3.32}$$

$$\mathbf{R}_\mathbf{t}^*(\mathbf{ijk}) = 2 * \mathbf{R}_\mathbf{t}(\mathbf{ijk}), \tag{3.33}$$

leaving the growth factor β_t unaffected of intervention.

In modelling time of first feeding visit no information of abrupt changes in the time series is known. In fact it seems reasonable to assume that once the social hierarchy has been established the time of first visit for each sow is relatively stable according to the studies by Hunter et al. (1988) and Edwards et al. (1988a,b). However introduction of new sows to an established group of sows using electronic feed stations has been reported to result in high levels of aggression during the first 24 hours following introduction (Bokma and Kersjes, 1988; Hunter et al., 1989; Moore et al., 1993), thereby making probable that the frequent introduction of sows or gilts in dynamic groups might affect stability of social hierarchy as well as feeding order.

In practice introduction of new sows to the group often occur in accordance to a weekly schedule and thus the probability of disturbances in time of first visit is increased on these days. To include this increased uncertainty in the model, evolution variance is increased by a factor 2 as in equation 3.33, on the days where sows are introduced, whereas the level are unaffected $\mathbf{a}_\mathbf{t}^*(\mathbf{ijk}) = \mathbf{a}_\mathbf{t}(\mathbf{ijk})$.

3.4 Results

Due to the unsuccessful data recording, only time series starting during the first 21 days following a sow's mating are included in the analysis. A total of 535 time series, comprising more than 20000 observations, have been analyzed. 28 of the time series are known to derive from unsuccessfully mated sows. However only 20 of these time series are useful since 8 of the sows have been removed from gestation or data recording has been broken down before the second registered mating date.

Modeling eating behaviour by the MP-DLMs directly results in specification of the probability of each observation to be described by the normal or outlier models. Since deviations in eating behaviour is assumed to result in outlying observations, probabilities of the outlier models at each time step is of particular interest. To illustrate the results of the multi-proces models the time series of a single sow showing some deviations in time of first feeding visit is presented in (a) of Figure 3.2. Part (b) an (c) shows the non-filtered probabilities of the normal and outlier models respectively, and part (d) the 1-step back filtered probability of the outlier model. When studying Figure 3.2 it appears that the observation on 21-08-1999 is identified as an outlier by a probability of approximately 90 pct. (part (c)) corresponding to a probability of the observation to be normal of approximately 10 pct. (part (b)). Applying the 1-step back filtering the observation on 21-08-1999 is identified as an outlier by approximately 70 pct. probability (part (d)).

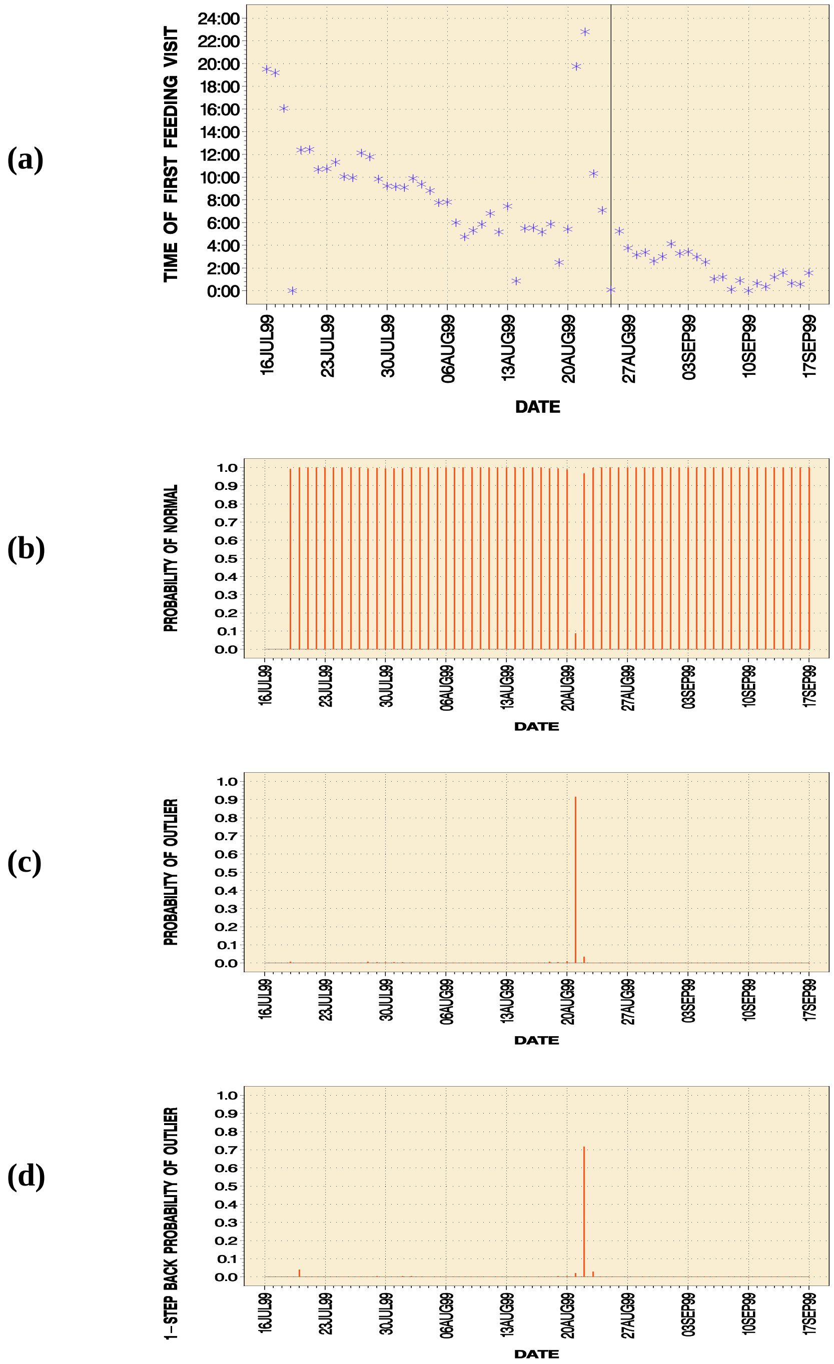


Figure 3.2: Results of the MP-DLM analysis of time of first feeding visit. (a) shows the time series whereas (b), (c) and (d) show the probabilities of the individual observations to be described by either the normal or outlier models. The horisontal line in (a) indicates the date of mating.

The reason to perform the back step filtering or smoothing is to increase certainty of identifying the individual observations to be either normal or outlying. Although the probability of the outlier model has decreased by the 1-step back filtering, the certainty of probability estimate has increased, since the 1-step back probability of the observation at 21-08-1999 is based on the observation on 22-08-1999 and all prior observations. Examining the observation on 22-08-1999 with the time of first feeding visit at 22.45, it seems clear that the deviation of this observation exceeds deviation of the previous observation. Two consecutive observations that deviates, might imply a new level, and the belief in the first deviating observation at 21-08-1999 to be an outlier is decreased if the next observation is outlying too.

Studying Figure 3.2 might seem to reveal an additional observation on 19-07-1999 that deviates markedly. However this observation is identified as a normal observation questioning the possibilities of the MP-DLM to identify outliers. Remembering that the first three observations are used in the reference analysis to estimate the initial information D_0 (Section 3.3.2), the observation on 19-07-1999 becomes the first observation to be included in modelling by the multi-process model. Using only three observations in estimating parameters $\mathbf{m_0}$, $\mathbf{C_0}$ and S_0, these observations greatly influence the variance estimate $\mathbf{C_0}$, which is of decisive importance in modelling of the first observations. The greater difference in observations the greater variance estimate, and as a result greater adaptive coefficient $\mathbf{A_t}$, increasing weight applied to the latest observations.

Also in modelling daily feed intake probabilities of deviations is directly specified. Studying the time series of daily feed intake of the same sow as in Figure 3.2 also indicate some deviations identified by probabilities exceeding 90 pct. In (a) of Figure 3.3 the time series of daily feed intake is shown, in part (b) and (c) the non-filtered probabilities of normal and outlier models respectively and in part (d) the 1-step back filtered probabilities of the outlier model are shown.

On 21-08-1999 a deviation is identified by a probability of more than 90 pct., which is actually at the same day as the deviation in time of first feeding visit is identified. By studying the effect of the 1-step back filtering, the probability of the deviation on 21-08-1999 is increased, although this hardly can be seen from the figure.

Of major concern in this study is the eating behaviour of unsuccessfully mated sows in order to be able to use eating behaviour as an indicator of oestrus. The time series in Figure 3.2 and 3.3 originate from one of the unsuccessfully mated sows. The horisontal lines mark the registered mating date (25-08-1999) and it is obvious that the time of first feeding visit as well as the daily feed intake deviate in the days before oestrus and mating. Studying the results of the rest of the unsuccessfully mated sows, reveal sows showing markedly deviations in one or both of the properties of eating behaviour around the second registered mating

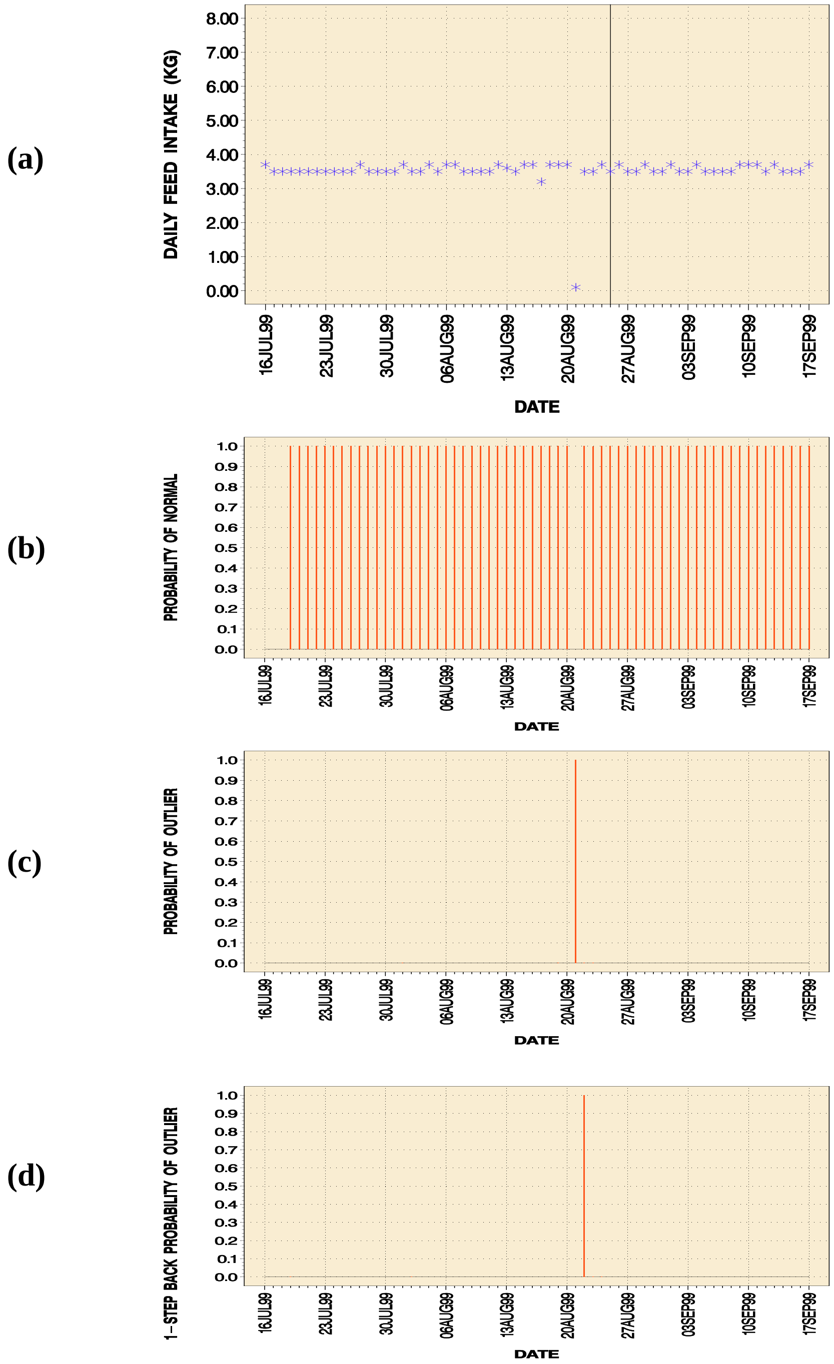


Figure 3.3: Results of the MP-DLM analysis of daily feed intake. (a) shows the time series whereas (b), (c) and (d) show the probabilities of the individual observations to be described by either the normal or outlier models. The horisontal line in (a) indicates the date of mating.

date. However not all of the sows show deviations in eating behaviour before oestrus, that can be identified by the MP-DLMs.

3.4.1 Evaluating the MP-DLMs as an alarm system

One of the most important properties of alarm systems might be the reliability. Alarm systems giving to many alarms might decrease the attention paid to the alarms, whereas to few alarms decreases benefit of the alarm system. These two properties can be specified by the sensitivity and specificity, that express the proportion of the true-positive alarms and the proportion of the true-negative alarms respectively (Enevoldsen, 1993), with a positive alarm defined as an identified deviation in eating behaviour in the days before oestrus.

When defined what triggers an alarm it must be specified when the alarm is triggered. One way to define this is by specifying certain threshold values that must be exceeded. For illustration in the following, a threshold value for the non-filtered outlier probability of 0.5 must be exceeded for the outlying observation to be regarded as a true deviation in eating behaviour. Since the back step filtering increases the certainty of outliers, the threshold values for the 1- and 2-step back filtered outlier probabilities may be increased and are set to 0.7 and 0.9 respectively. By this threshold values for the alarm system, the number of identified deviations in time of first feeding visit and daily feed intake is summarized in Table 3.2. In the table the total number of identified deviations as well as the number of identified deviations caused by oestrus is shown, where deviations caused by oestrus is defined as deviations in eating behaviour occurring within 7 days before oestrus.

Table 3.2: The total number of deviations and the number of deviations before oestrus in unsuccessfully mated sows in time of first feeding visit and daily feed intake identified by the 0-, 1- and 2-step back filtered probabilities. Threshold values are set to 0.5, 0.7 and 0.9 for the 0-, 1- and 2-step back filtered probabilities, respectively.

	No back step filtering		**1-step back filtering**		**2-step back filtering**	
	Total deviations	Oestrus deviations	Total deviations	Oestrus deviations	Total deviations	Oestrus deviations
Time of first feeding visit	58	1	40	0	23	0
Daily feed intake	3233	17	3079	15	2891	16
Daily feed intake (failure corrected)	731	9	1191	9	1263	10

One of the most conspicuous results in Table 3.2 concerns the daily feed intake, due do the number of identified deviations. This huge number of identified deviations in daily feed intake must be remembered to occur due to missing observation, which is regarded as sows not eating all of their feed ration. However some of these missing observations is due to failure in data recording and removing the deviations caused by data recording failure corrects the number of identified deviations as shown in the table. Correcting the deviations identified however also affects the number of identified deviations caused by oestrus, as well as the number of deviations in daily feed intake still seems large.

Studying the results of both time of first feeding visit as well as daily feed intake, a relative small proportion of the identified deviations are related to the unsuccessfully mated sows. This small proportion of true-positive alarms result in sensitivity to be low (<0.02) in both properties of eating behaviour, whereas the specificity becomes large (>0.99) since only observations not identified as outliers in time series of unsuccessfully mated sows in the 7 day period before expected oestrus are regarded as false-negative alarms.

The increased certainty obtained by the back step filtering neither seems to have effect in increasing the proportion of identified deviations derived from unsuccessfully mated sows. Changing the threshold values might give a better result. However increasing threshold values probably just results in fewer deviations identified among both successfully and unsuccessfully mated sows, whereas decreasing threshold values results in more deviations identified. Changing the relation between threshold values of the 0-, 1- and 2-step back filtering probabilities might improve the results but has not been paid further attention.

Deviations in the two time series do not necessarily relate to different sows, and in Table 3.3 the number of unsuccessfully mated sows identified is shown. From the table it is seen that only a single unsuccessfully mated sow is identified by deviations in time of first feeding visit if probabilities are not smoothed. Correcting the identified deviations in daily feed intake, between 5 and 7 of the unsuccessfully mated sows is identified depending of the back step filtering. If the back step filtering is ignored 9 different sows are identified by deviations in one of the time series. As for the number of identified deviations in Table 3.2 it is seen that the number of unsuccessfully mated sows identified only make out a small proportion of the total number of identified sows and that the use of back step filtering only slightly increases the proportion of identified unsuccessfully mated sows.

Hunter et al. (1988) and Edwards et al. (1988b) reported greater stability in feeding order of sows eating early in feeding cycle compared to sows eating late. Due to this it seems interesting whether the 9 different unsuccessfully mated sows identified by deviations in eating behaviour ate earlier than the unsuccessfully mated sows not identified. Analyzed by a general linear model with identified/not

Table 3.3: The number of different sows showing deviations in eating behaviour identified by the 0-, 1- and 2-step back filtered probabilities. Threshold values are set to 0.5, 0.7 and 0.9 for the 0, 1- and 2-step back filtered probabilities, respectively.

	No back step filtering		**1-step back filtering**		**2-step back filtering**	
	Total sows	Oestrus sows	Total sows	Oestrus sows	Total sows	Oestrus sows
Time of first feeding visit	52	1	37	0	23	0
Daily feed intake	406	9	375	8	363	9
Daily feed intake (failure corrected)	269	5	332	6	323	7

identified sows and gestation pen as fixed effects and sow as random effect, a significant ($p < 0.001$) difference in time of first feeding visit has been found between the identified and not identified sows, which support the findings of Hunter et al. (1988) and Edwards et al. (1988b).

Compared with the total number of identified deviations in unsuccessfully mated sows it seems that a rather small proportion of the deviations occur in the 7 days period prior to oestrus. Studying an extended period some sows show markedly deviations in eating behaviour approximately 21 or 42 days before registered mating dates, see Figure 3.4. By the identification of these deviations it might have been possible to mate the sows earlier and thereby increase productivity. The few examples of eating behaviour deviating in one oestrus cycle but not in the next might be caused by a decreased response to rises in oestrogens with increasing number of oestrus (Andersson et al., 1984), and monitoring of eating behaviour in relation to oestrus detection ought to be paid special attention or restricted to a short period following mating, rather than the entire period of pregnancy.

If some of the false-positive identified deviations have to be eliminated, performance of the modelling may be improved. One way might be by inclusion of an additional property of eating behaviour. For illustration, the time series of feeding time has been analyzed by a MP-DLM similar to the one used in modelling time of first feeding visit, except that intervention effects have been adjusted to handle an expected level shift in feeding time due to increased feed allowance on day 85 of pregnancy. By inclusion of this property three additional unsuccessfully mated sows are identified in the 7 days period before registered mating, resulting in a total of between 12 different unsuccessfully mated sows identified if the back step filtering is ignored.

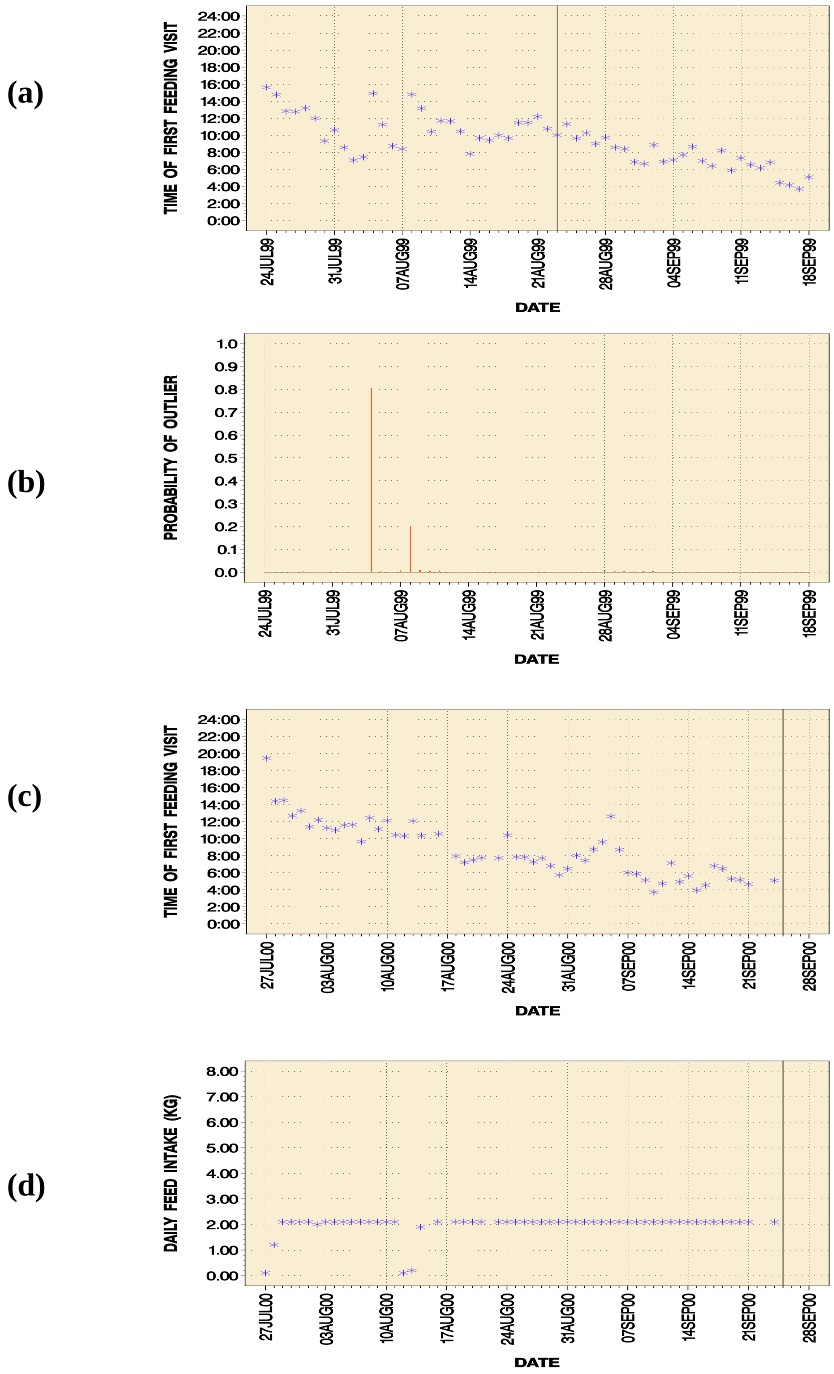


Figure 3.4: Time series showing deviations in eating behaviour approximately 21 or 42 days before registered mating dates. In (a) time of first feeding visit is shown with the corresponding probabilities of the individual observations to be outlying in (b). (c) and (d) show time of first feeding visit and daily feed intake of a different sow. The horisontal lines indicate dates of mating.

Another way to increase sensitivity is by combining information from several time series as suggested above. Since two properties are used in describing eating behaviour, deviations might affect both of the time series. In the time series of daily feed intake, all of the sows not eating their feed ration are identified as outliers, resulting in a huge number of deviations in daily feed intake. In order for the deviation in daily feed intake to be paid attention in relation to oestrus detection, time of first feeding visit and daily feed intake have to deviate simultaneous. With deviations in daily feed intake identified, the threshold value for the time of first feeding visit may be decreased as the deviation in daily feed intake indicates that the eating behaviour might deviate. By defining simultaneous deviations in time of first feeding visit as occurring within 2 days before or after deviations in daily feed intake and decreasing threshold values for the time of first visit by 0.2, combination of time series seems to result in decreased number of sows identified, cf. Table 3.4. However also the number of unsuccessfully mated sows identified are reduced.

Table 3.4: The number of different sows showing deviations in eating behaviour identified by combining information from several time series. Combination of time series allow threshold values to be decreased, with the reduction set to 0.2.

	No back step filtering		**1-step back filtering**		**2-step back filtering**	
Combination	Total sows	Oestrus sows	Total sows	Oestrus sows	Total sows	Oestrus sows
Time of first visit/ Feed intake	18	1	19	1	10	0
Time of first visit/ Feeding time	24	1	18	0	10	0
Feed intake/ Feeding time	125	2	152	2	123	2
Time of first visit/ Feed intake/Feeding time	9	1	5	0	2	0

Altering the combining of time series to include feeding time new possibilities of combinations arise, in that daily feed intake may be combined by either time of first feeding visit or feeding time as well as combination of time of first feeding visit and feeding time is possible. Finally all of the three time series may be combined enabling a further reduction of threshold values for all of the time series, cf Table 3.4. Combining all of the three time series, results in a markedly decreased sensitivity as only up to a total 9 sows are identified. Although sensitivity is increased it still remains low with only 1 of the unsuccessfully mated sows identified within 7 days before registered mating dates with no filtering applied to the probabilities.

3.5 Discussion

The identified deviations prior to mating of the sows might indicate a relationship between eating behaviour and the occurrence of oestrus although deviations in eating behaviour also seems to occur independently of oestrus. Occurrence of oestrus is determined on the basis of the registered mating dates by the manager, thereby defecting uncertainty to the accurate time and duration of oestrus and as well to the assessment of deviations occurring in relation to oestrus.

One of the major problems in oestrus detection by modelling eating behaviour seems to be that the sensitivity is low resulting in false-positive identified deviations in eating behaviour. The reason for these insufficiencies might relate to either model design or to instabilities in expected biological correlations between oestrus and eating behaviour.

When an outlying observation is identified it is of great importance to determine whether the deviation is caused by oestrus or not, which can be done by specifying certain threshold values in the back step filtered probabilities that must be exceeded. The threshold values must be estimated in accordance to the applied model and take into account that the back step filtering increases certainty and allows the threshold values to be increased. However not only identification of deviations but also the time of identification deviations are of great importance, since deviations in eating behaviour identified after or in the late oestrus is of less use due to reduced production performance.

In the present study two properties of eating behaviour are used in describing eating behaviour and inclusion of a third is briefly reviewed. However several other properties exist that in some way describes eating behaviour and due to the restrictive feeding of sows in ESF systems, a decreased appetite might be expressed in one or more of these properties. One way of combining information from several time series is discussed in the previous section. Another way is by the use of Dynamic Linear Models, enabling information from several time series to be combined by the use of covariances, that are dynamically updated in accordance to the theory of DLMs. Since eating behaviour and social hierarchy apparently seems to be correlated as suggested by Hunter et al. (1988) and Edwards et al. (1988b), it additionally might be interesting to combine information from different sows by use of covariances, which enable modelling of individual sows' eating behaviour by taking the eating behaviour of the other sows in the group into account. Both kind of combining information can be included in a multi variate dynamic linear model as described in West and Harrison (1997, chap. 16).

In modelling time of first feeding visit, the use of a Multi-Process Dynamic Linear Model might also be a cause of the inadequate results. By studying the time series relating to the unsuccessfully mated sows, it seems that deviations in time of first feeding visit last several days, hence decreasing the back step filtered probabilities of identifying these deviations. Alternatively the use of a Dynamic Linear Model combined with a cusum chart as done by Madsen (1999) might be more suitable in identifying the deviations in time of first feeding visit caused by oestrus.

In designing the model, one of the major disciplines is estimation of parameters. Several of the parameters in the applied multi-process models are updated continuously, hence decreasing the number of parameters to be estimated manually. However not all of the parameters can be updated continuously, in example prior probabilities of normal and outlying observations, which must be specified directly. In the present study it is known that 15 pct. of the sows are unsuccessfully mated at their first mating, and it is unknown whether these sows return to oestrus regularly within the defined 6 days period around day 21 (Section 3.3.1). It is assumed that 80 pct. of the unsuccessfully mated sows return to oestrus regularly, whereas the last 20 pct. return to oestrus irregularly. If this assumption however is not in agreement with the actual data, inadequacies in the MP-DLM might be experienced, due to inexact specification of prior probabilities. As an alternative to the constant prior probabilities, Markov probabilities may be applied to the MP-DLMs (West and Harrison, 1997), causing the model combinations to be dependent of the previous model combinations. However the Markov transition probability matrix have to be estimated, which might be more difficult than specifying constant prior probabilities.

The differences in deviations in eating behaviour among sows outline the fact that the effects of oestrus on eating behaviour varies among individual sows. Deviations in time of first visit and daily feed intake prior to oestrus apparently only occur for some sows, suggesting that the restrictive feeding of sows or the social hierarchy (Hunter et al., 1988; Edwards et al., 1988b) possibly cover up some of the changes in eating behaviour.

In a study on the eating behaviour of individual sows using electronic feed stations, Eddison and Roberts (1995) showed that on average 79 pct. of the sows ate more than 0.95 of their daily ration in a single visit. The last 21 pct. of the sows ate on average only 0.34 of their daily feed ration in their first feeding visit, suggesting that sows either eat in a single large meal or several smaller meals (Eddison and Roberts, 1995). Further it was analyzed if the 21 pct. of the sows eating in several visits was caused by a few sows, or whether all of the sows showed some degree of variation. By studying in how many of an individual sow's first feeding visits, all of the daily ration was eaten, Eddison and Roberts

(1995) found that only 26 out of 101 sows ate all of their ration in more than 90 pct. of their first feeding visits. The results showed that on most occasions sows ate all of their ration in a single visit but also that no sow ate all of the daily ration in every occasion, suggesting that the individual sows display different variability in eating behaviour (Eddison and Roberts, 1995). This variation in individual eating behaviour might be a major cause of the inadequate performance of the MP-DLMs, since prior probabilities are estimated based on an assumption that only unsuccessfully mated sows deviate in eating behaviour.

Correlation between oestrus and changes in eating behaviour is assumed in this project, and a reported decreased voluntary feed intake during the week of oestrus (Friend, 1971, 1973) seems to support the existence of such a correlation. Forbes (1995) suggested the changes in appetite to be due to increased blood level of oestrogens prior to standing oestrus. Concerning development and duration of oestrus, considerable variation between individual sows in addition occur, where time from onset of oestrus to ovulation have been found to be longer in sows with longer oestruses (Einarsson et al., 1998). Also large variation have been reported in the interval from oestradiol peak to onset of oestrus, making it difficult to use endocrine parameters in predicting oestrus (Einarsson et al., 1998). As a consequence this difficulties also might be reflected in eating behaviour. However monitoring of eating behaviour is not necessarily supposed to be used in an accurate prediction of oestrus onset, and identifying changes in eating behaviour before onset of standing oestrus might be adequate.

Increases in oestrogens normally occur in the pro-oestrus, and factors affecting the pro-oestrus might be of importance to the correlation between oestrus and appetite. Einarsson et al. (1998) reported a decreased response to oestrogens with earlier weaning, and in a study on the effect of the interval from weaning to oestrus (IWO) on duration of pro-oestrus, Sterning (1995) reported a positive correlation. In addition duration of pro-oestrus have been reported to decrease with increasing oestrus number, probably due to changes in the receptor mechanisms of oestrogen in the vulva (Andersson et al., 1984). The effects on pro-oestrus and oestrus implies the complex regulation of oestrus and emphasize the difficulties in specifying the period, where eating behaviour is suppose to deviate due to oestrus. Perhaps this complexity might be responsible for elimination of the assumed correlation between oestrus and eating behaviour for some sows.

Studying the seasonal effects on oestrus Sterning (1995) only reported little influences, except for the duration of pro-oestrus that was significantly shorter in the period of long day length (21/3-20/9). A seasonal effect on eating behaviour, effected either through light (Forbes, 1995) or temperature (Lynch, 1989), might also exist, perhaps causing a severe effect of oestrogens to be needed to decrease appetite. The extend to which these factors influence the results of the present study has however not been paid much attention.

In using eating behaviour in oestrus detection the system naturally becomes dependent of other influences on eating behaviour than oestrus, i.e. temperature, light and disease, that might cause simultaneous deviations in the properties of eating behaviour. As mentioned above also the restrictive feeding of sows might cover up some of the influences on eating behaviour, which might also be an explanation of the great variability in individual sows' eating behaviour. At last the findings of a significant difference in time of first feeding visit between unsuccessfully mated sows identified by deviations in eating behaviour and unsuccessfully mated sows not identified might indicate greater stability in eating behaviour of sows eating early in the feeding cycle as suggested by Hunter et al. (1988).

In order to improve reliability of an oestrus detection system additional information from properties independent of eating behaviour may be included. Bressers et al. (1991) investigated individual sows' number of visits to the boar pen in order to detect oestrus automatically, but concluded that the sensitivity in detecting oestrus was to low. However combining information from eating behaviour and visits to the boar pen might improve the detection of oestrus due to the independency between eating behaviour and visits to the boar pen.

Enhancement of management routines in electronic sow feeding systems by a model based system for oestrus detection seems to need further development. The correlation between oestrus and eating behaviour, model design and the use of information independent of eating behaviour might seem to be of special interest in future studies.

3.6 Conclusion

In using eating behaviour to identify oestrus it seems possible that oestrus affects eating behaviour by decreasing appetite and cause deviations in both time of first visit and daily feed intake. However deviations in eating behaviour also seems to occur independently of oestrus and makes the identification of deviations caused by oestrus difficult. The two Multi-Process Dynamic Linear Models used in modelling eating behaviour seem to be unreliable as a system to indicate oestrus.

Insufficiency in oestrus detection by modelling eating behaviour might be related to both inadequacies in model design as well as variability in eating behaviour of individual sows. Especially the individual variability in sows' eating behaviour are thought to be of major importance as well as inexact specification of prior probabilities. By inclusion of an additional property of eating behaviour as well as a simple combining of information from several time series, it has been illustrated that the number of false-positive deviations may be decreased, however also decreasing the number of identified deviations caused by oestrus.

In order to improve the model, considerations concerning model design, specification of prior probabilities and the benefit of using back step filtering seems to be necessary. As well the correlation between oestrus and eating behaviour and combination of information from several time series needs to be further examined.

Acknowledgement

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Chapter 4

General conclusion

In the present project the possibilities in identifying deviations in eating behaviour have been investigated and whether the identified deviations relates to the occurrence of oestrous. Studies on voluntary intake of sows and gilts have suggested a correlation between oestrus and decreased appetite supporting the idea of enhancing management routines concerning oestrus detection in group-housed sows by modelling eating behaviour.

Modelling of eating behaviour however might be difficult due to difficulties in defining eating behaviour. The detailed registration of sows' use of feed stations comprise information of the eating behaviour expressed through several properties of eating behaviour. The properties derived from recordings of sows' visits to the feed stations comprise the time of first feeding visit, daily feed intake, feeding time, number of total visits to the feed stations as well as the number of feeding and non-feeding visits.

Studying these properties reveals more or less stability in the properties of eating behaviour. If eating behaviour has to be used in oestrus detection, some form of stability has to occur in order to be able to identify deviations in eating behaviour. Based on plot of raw data it seems that the time of first feeding visit, daily feed intake, feeding time and number of feeding visit might be used in modelling eating behaviour. However eating behaviour is also affected by external influences, i.e. temperature and social hierarchy, and the complex situation might be a cause of individual variability in eating behaviour.

In an attempt to identify deviations in eating behaviour two Multi-Process Dynamic Linear Models (MP-DLMs) have been used in modeling eating behaviour. Eating behaviour was described by time of first feeding visit and daily feed intake and each of the properties was modelled by a MP-DLM. The multi-process models have been shown useful in modelling time series comprising both gradual and abrupt changes and in handling of variance components.

Modelling eating behaviour by the MP-DLMs directly resulted in specification of the probability of each observation to be either normal or outlying. Studying the results of the unsuccessfully mated sows, some sows seemed to show deviations in one or both of the properties of eating behaviour around the second registered mating date, whereas other sows showed no deviations in eating behaviour before oestrus, that could be identified by the MP-DLMs. Time series of the unsuccessfully mated sows are shown in Appendix A.

Studying the total number of deviations, a relative small proportion of the identified deviations were related to the unsuccessfully mated sows in both time series. This small proportion of true-positive alarms resulted in sensitivity to be low (<0.02), whereas the specificity was large (>0.99). The sensitivity and specificity express the proportion of the true-positive alarms and the proportion of the true-negative alarms respectively, with a positive alarm defined as an identified deviation in eating behaviour in the days before oestrus.

It was concluded that the applied models are unreliable in detecting oestrus. This unreliability might be caused by considerable individual variability in sows' eating behaviour and as a consequence inexact specification of model parameters.

Although the results may seem to support the existence of a correlation between oestrus and eating behaviour it must be concluded, that by the used Multi-Process Dynamic Linear Models too few of the identified deviations in eating behaviour relates to oestrus resulting in insufficiencies in detecting oestrus. The relative small amount of data relating to unsuccessfully mated sows combined with the few identified deviations might imply that these deviations are random, which however not has been paid further attention. Additionally it might be that the multi-process models are insufficient in modeling one or more of the time series and that different models might improve reliability of the oestrus detection. Concerning enhancement of management routines in electronic sow feeding systems it additionally must be concluded that the presented modelling of eating behaviour can not be used in oestrus detection and further studies are needed in examining the correlation between eating behaviour and oestrus as well as the possibilities in combining of information from several properties.

Appendix A

Eating behaviour of unsuccessfully mated sows

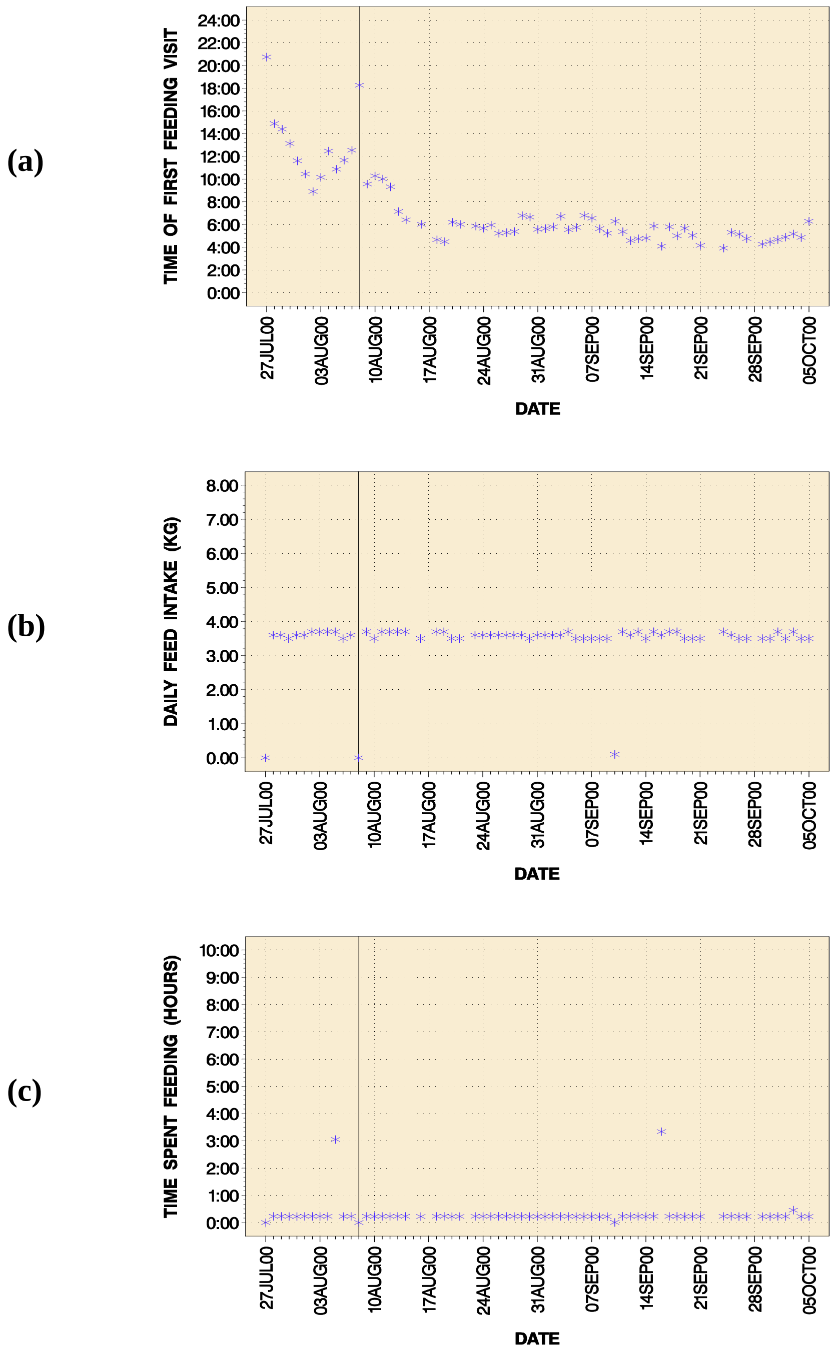

Figure A.1: Time series of sow 58 showing time of first feeding visit (a), daily feed intake (b) and feeding time (c). The horisontal lines indicate date of mating.

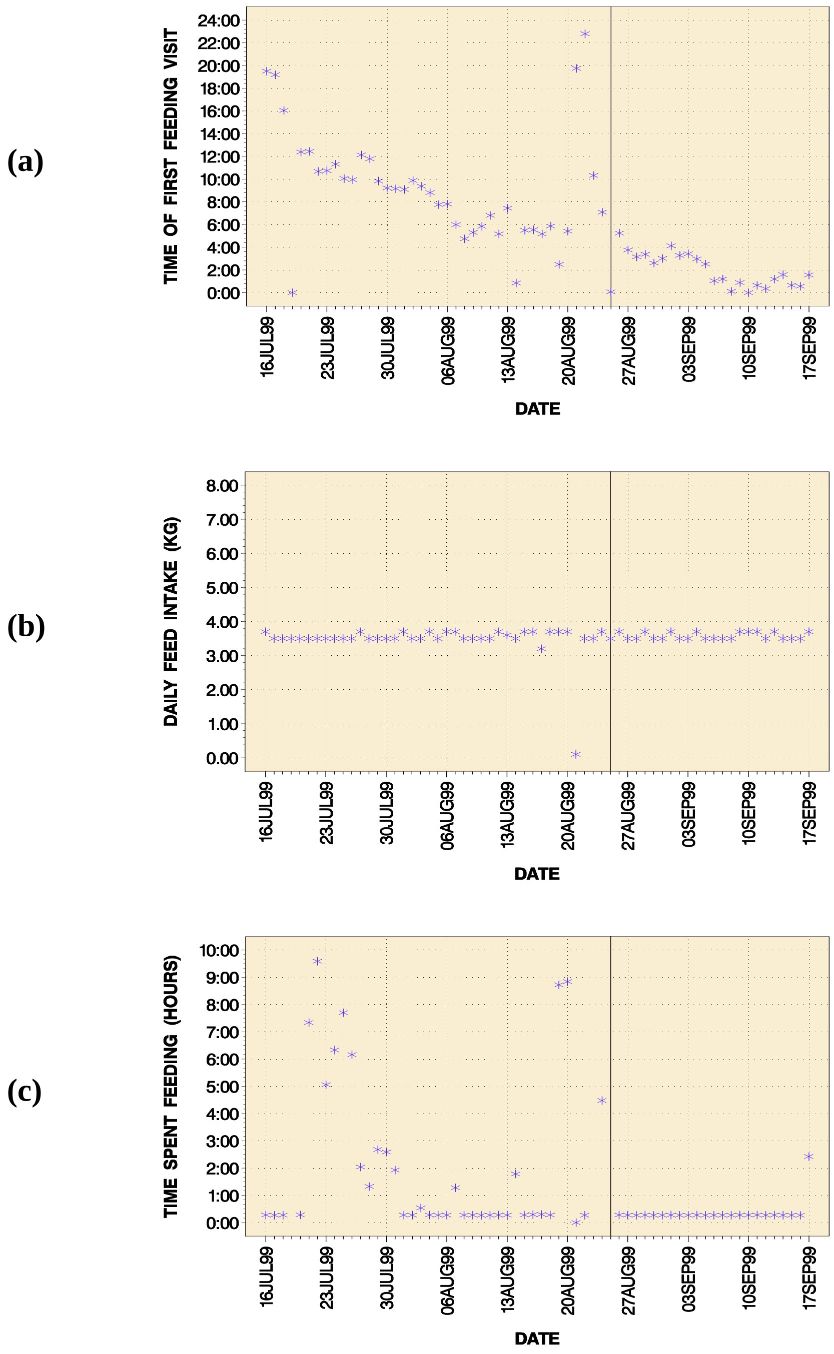

Figure A.2: Time series of sow 104 showing time of first feeding visit (a), daily feed intake (b) and feeding time (c). The horisontal lines indicate date of mating.

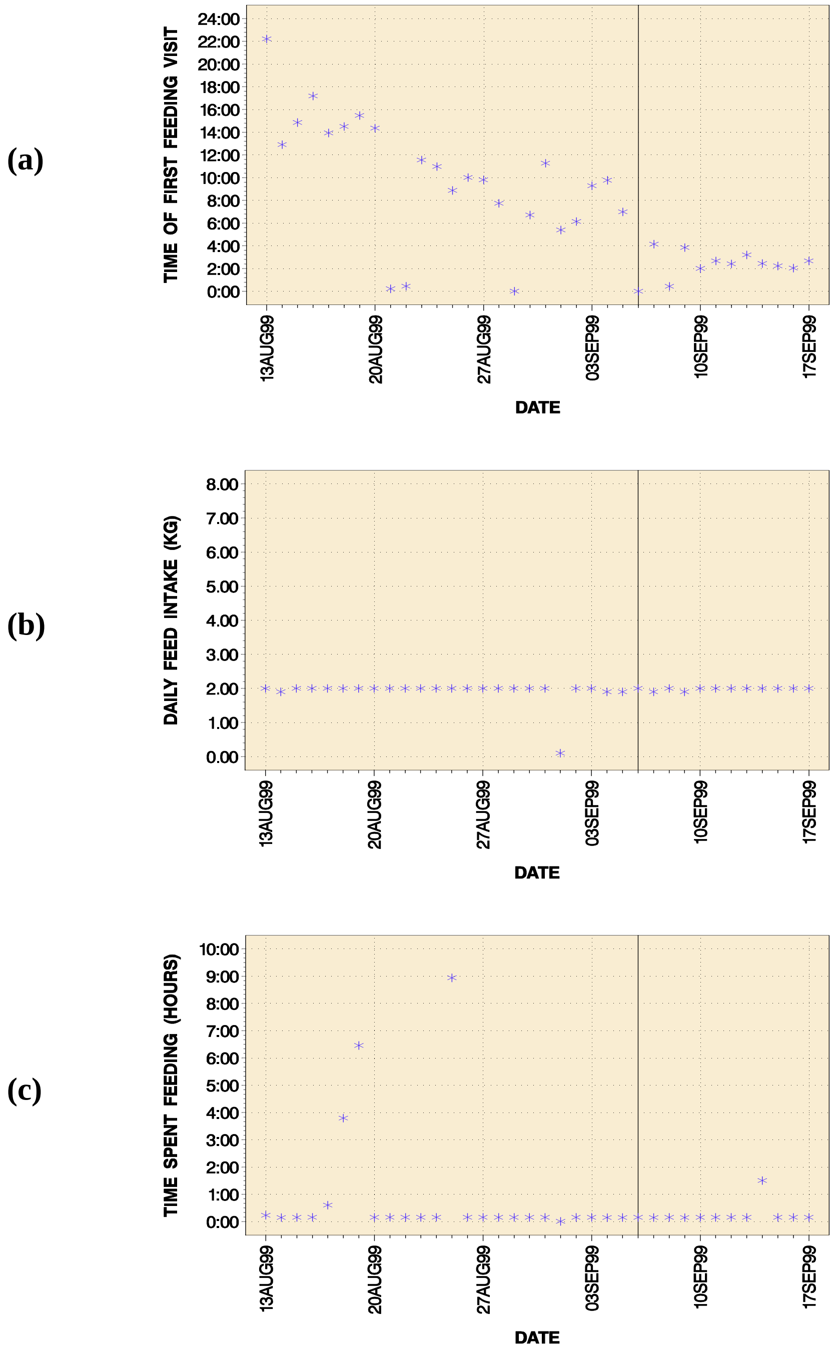

Figure A.3: Time series of sow 116 showing time of first feeding visit (a), daily feed intake (b) and feeding time (c). The horisontal lines indicate date of mating.

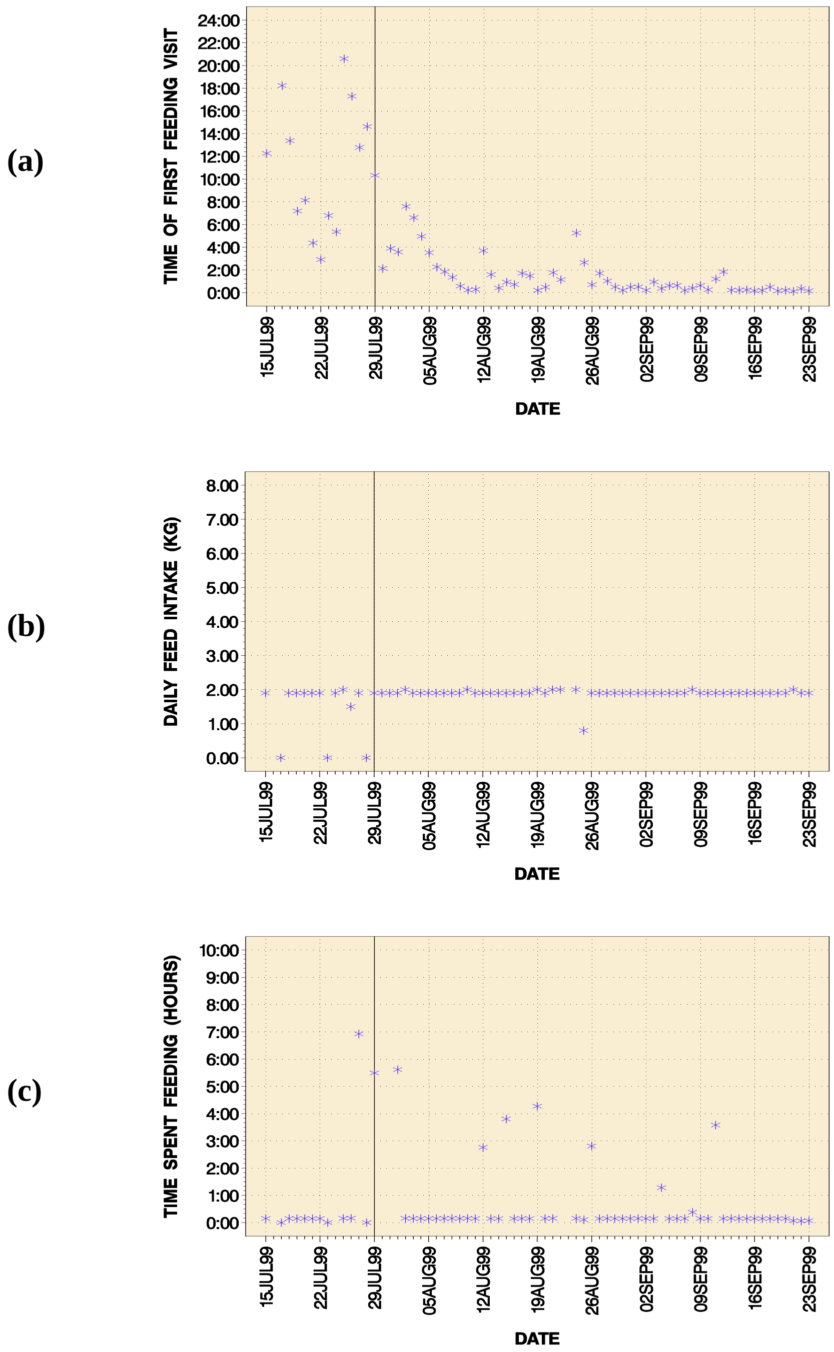

Figure A.4: Time series of sow 290 showing time of first feeding visit (a), daily feed intake (b) and feeding time (c). The horisontal lines indicate date of mating.

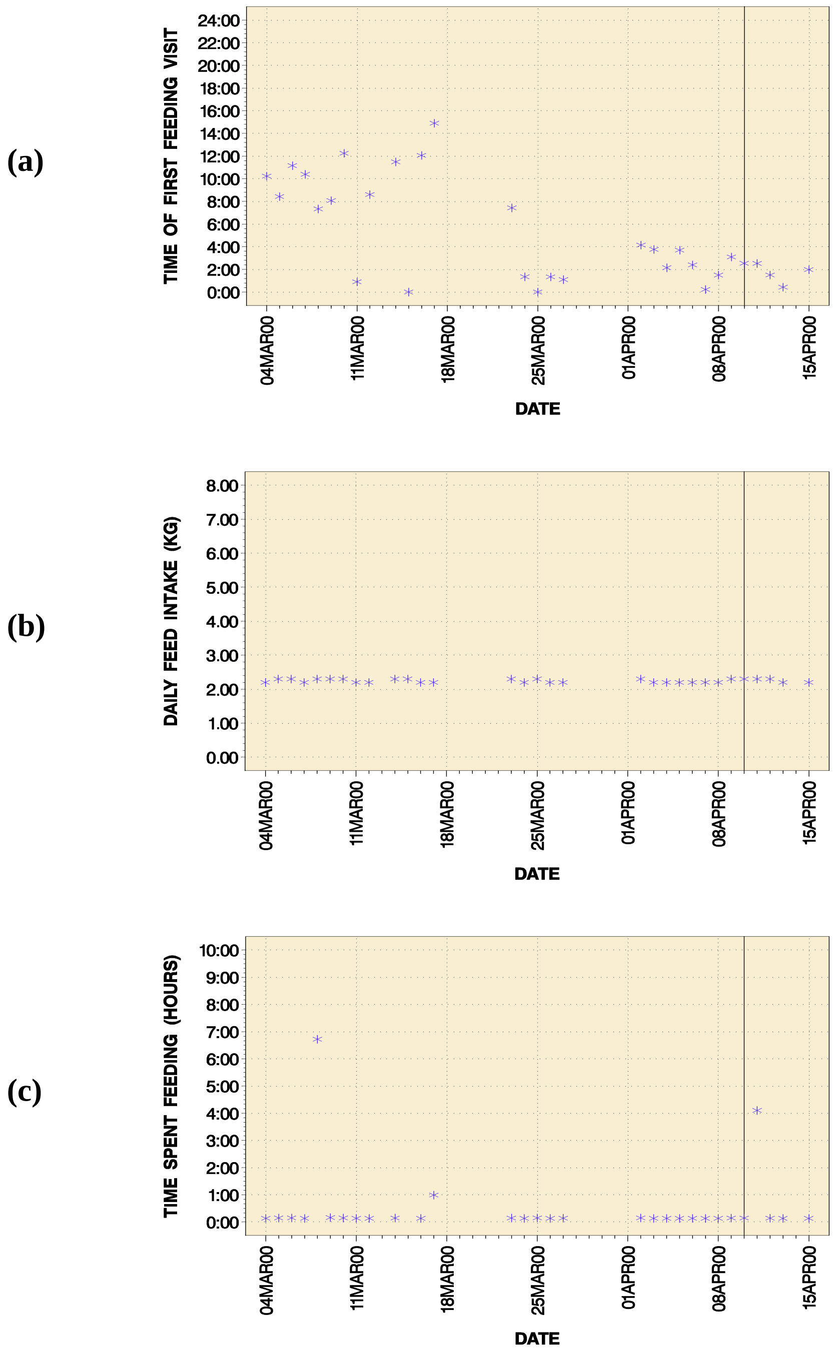

Figure A.5: Time series of sow 918 showing time of first feeding visit (a), daily feed intake (b) and feeding time (c). The horisontal lines indicate date of mating.

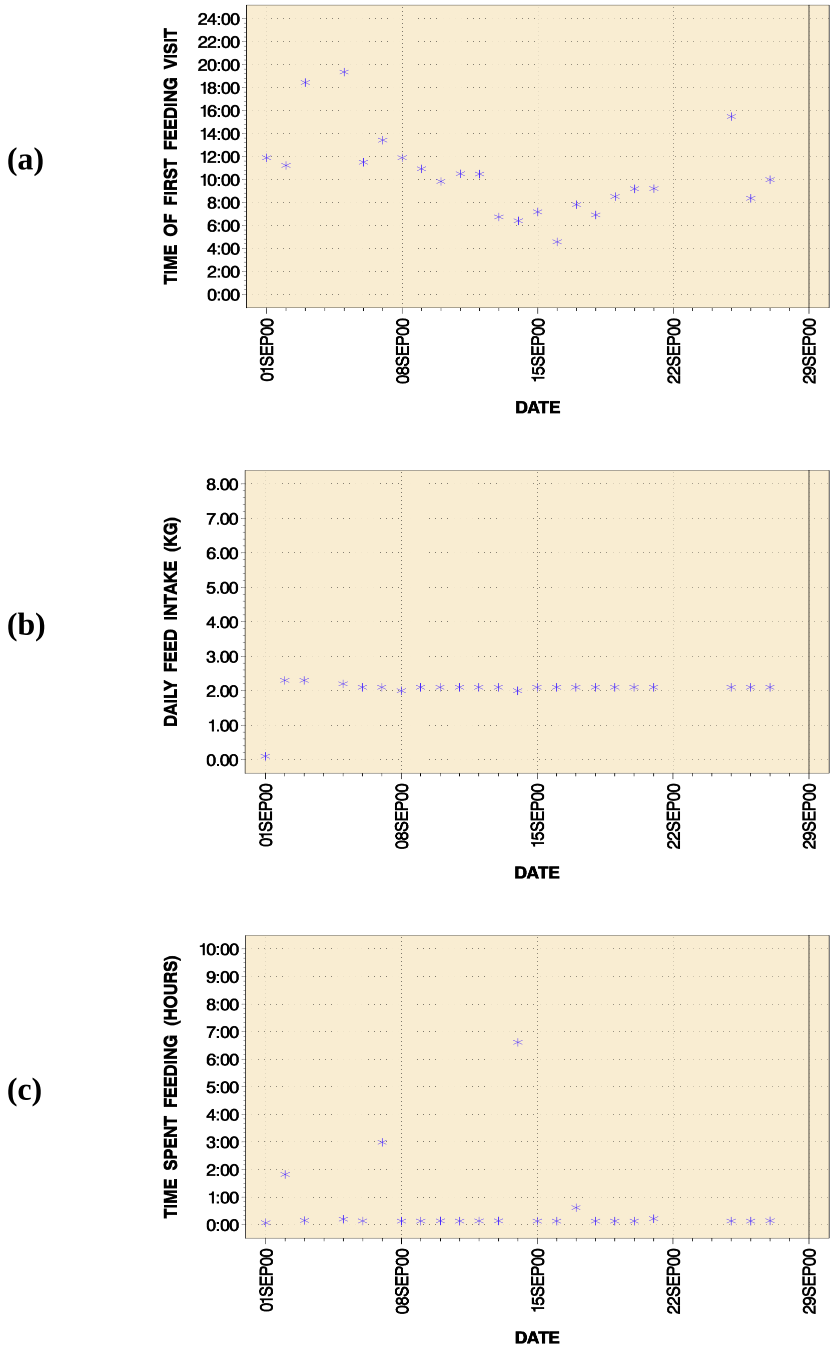

Figure A.6: Time series of sow 946 showing time of first feeding visit (a), daily feed intake (b) and feeding time (c). The horisontal lines indicate date of mating.

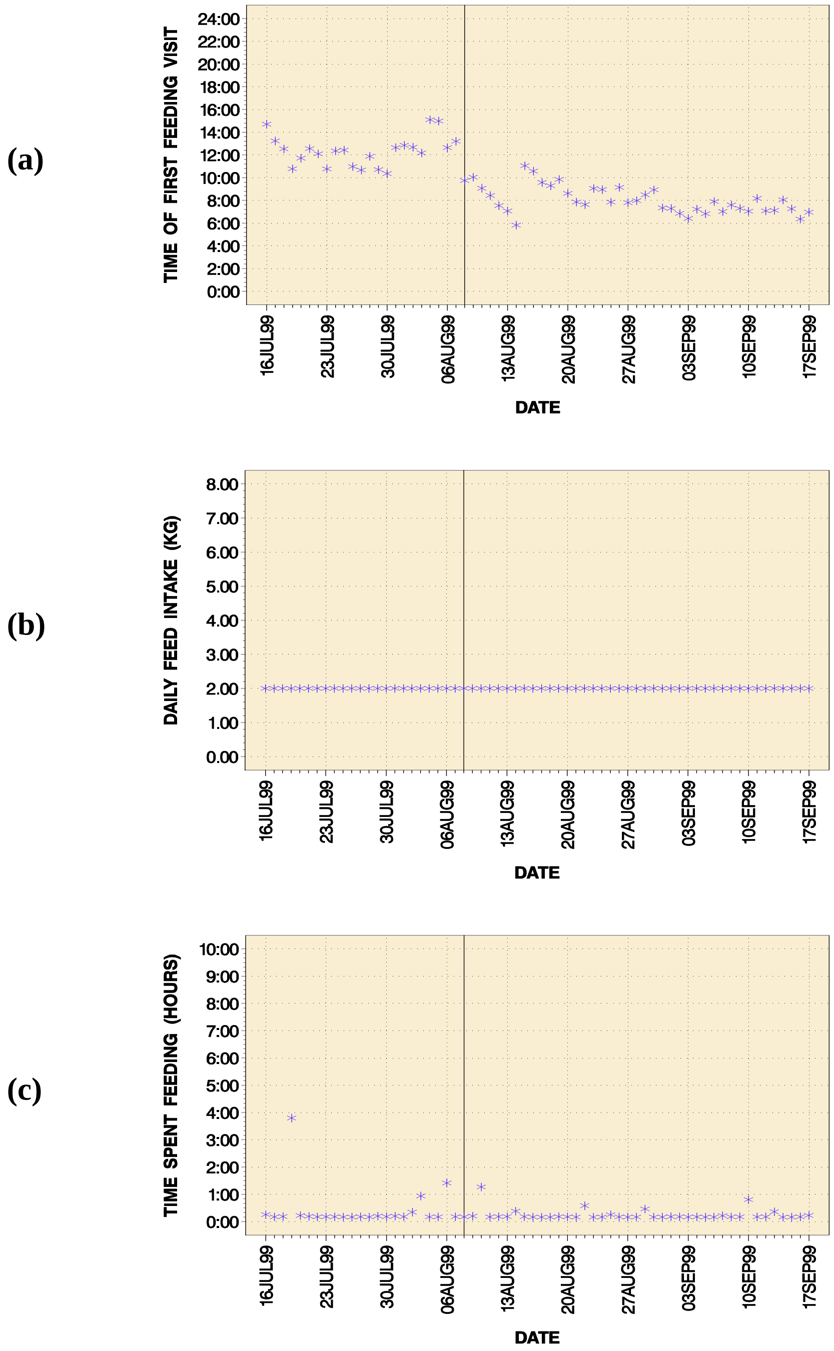

Figure A.7: Time series of sow 1001 showing time of first feeding visit (a), daily feed intake (b) and feeding time (c). The horisontal lines indicate date of mating.

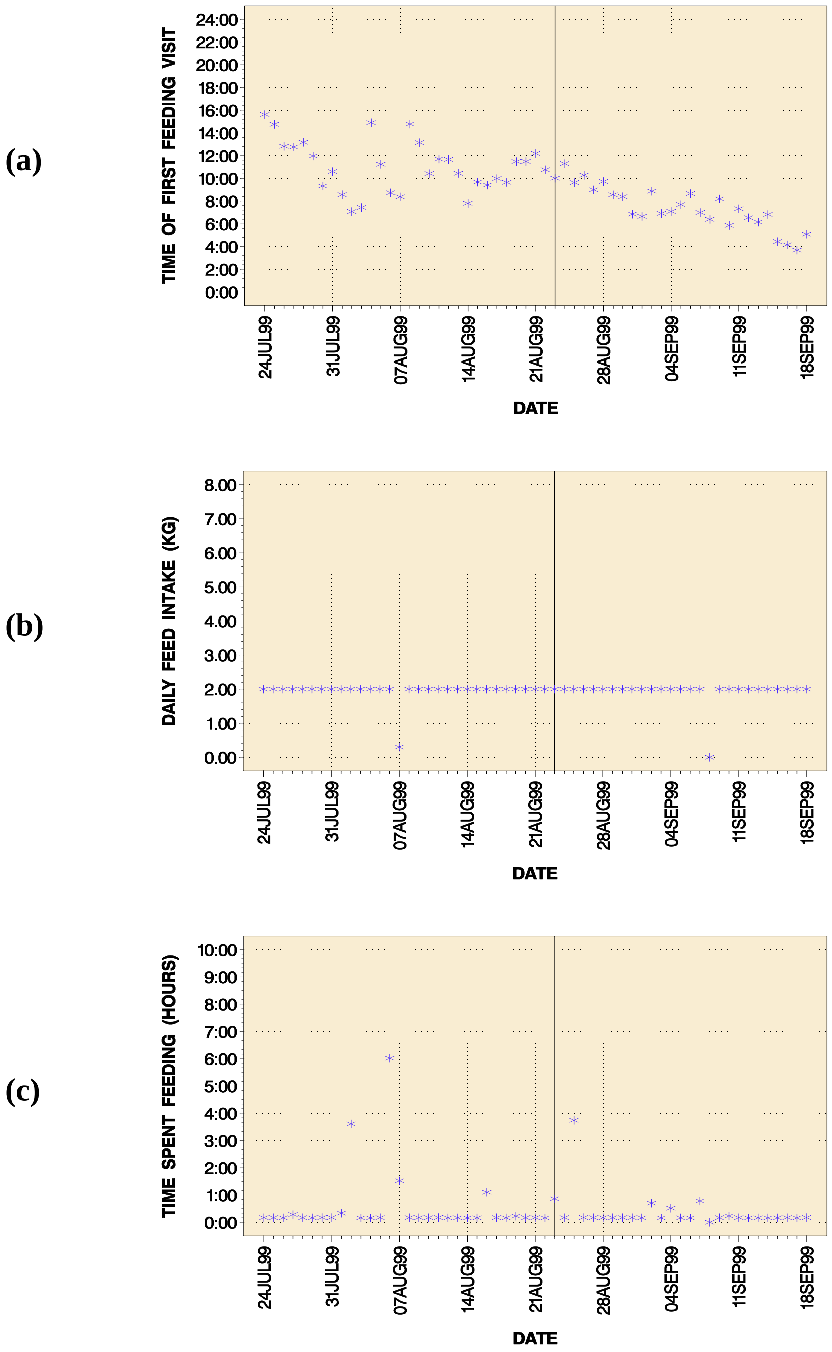

Figure A.8: Time series of sow 1043 showing time of first feeding visit (a), daily feed intake (b) and feeding time (c). The horisontal lines indicate date of mating.

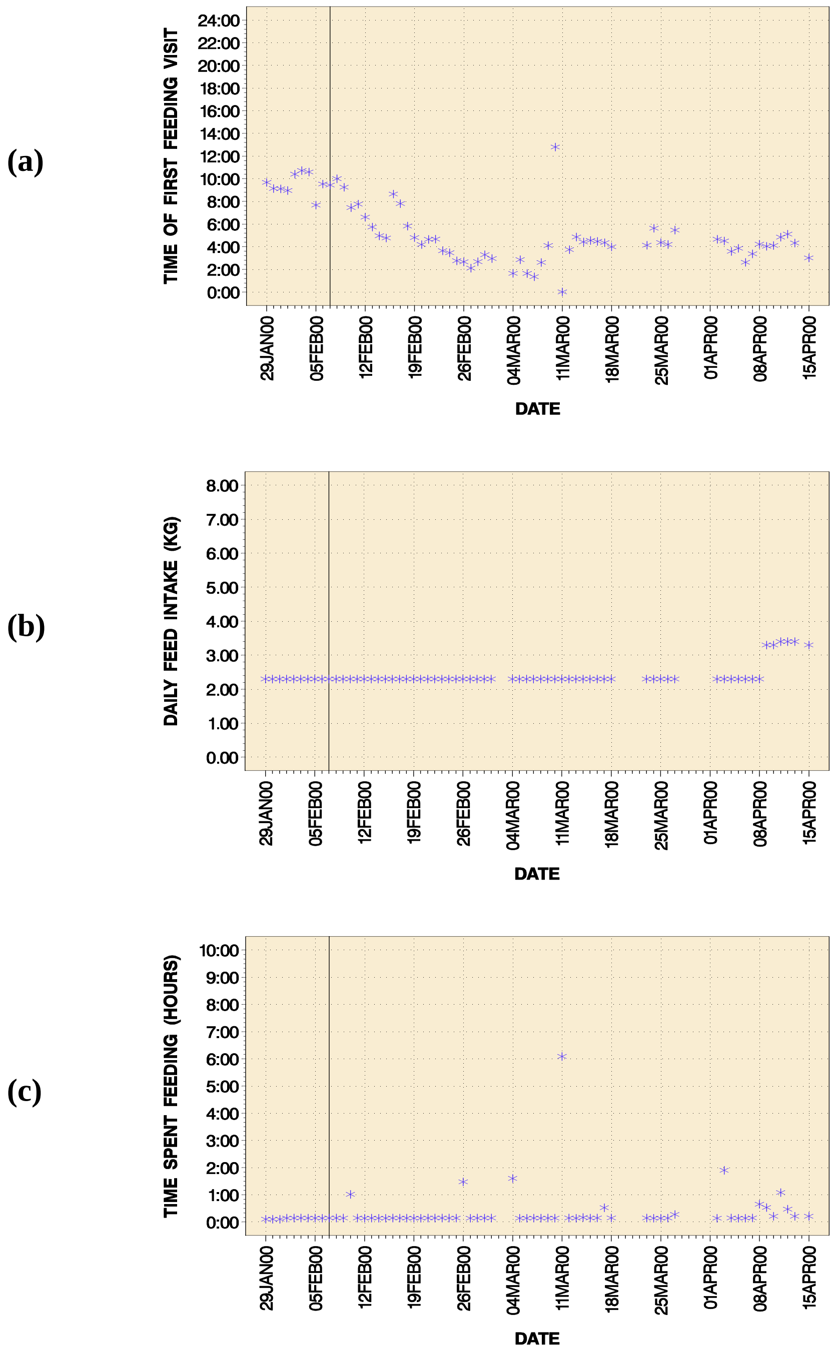

Figure A.9: Time series of sow 1059 showing time of first feeding visit (a), daily feed intake (b) and feeding time (c). The horisontal lines indicate date of mating.

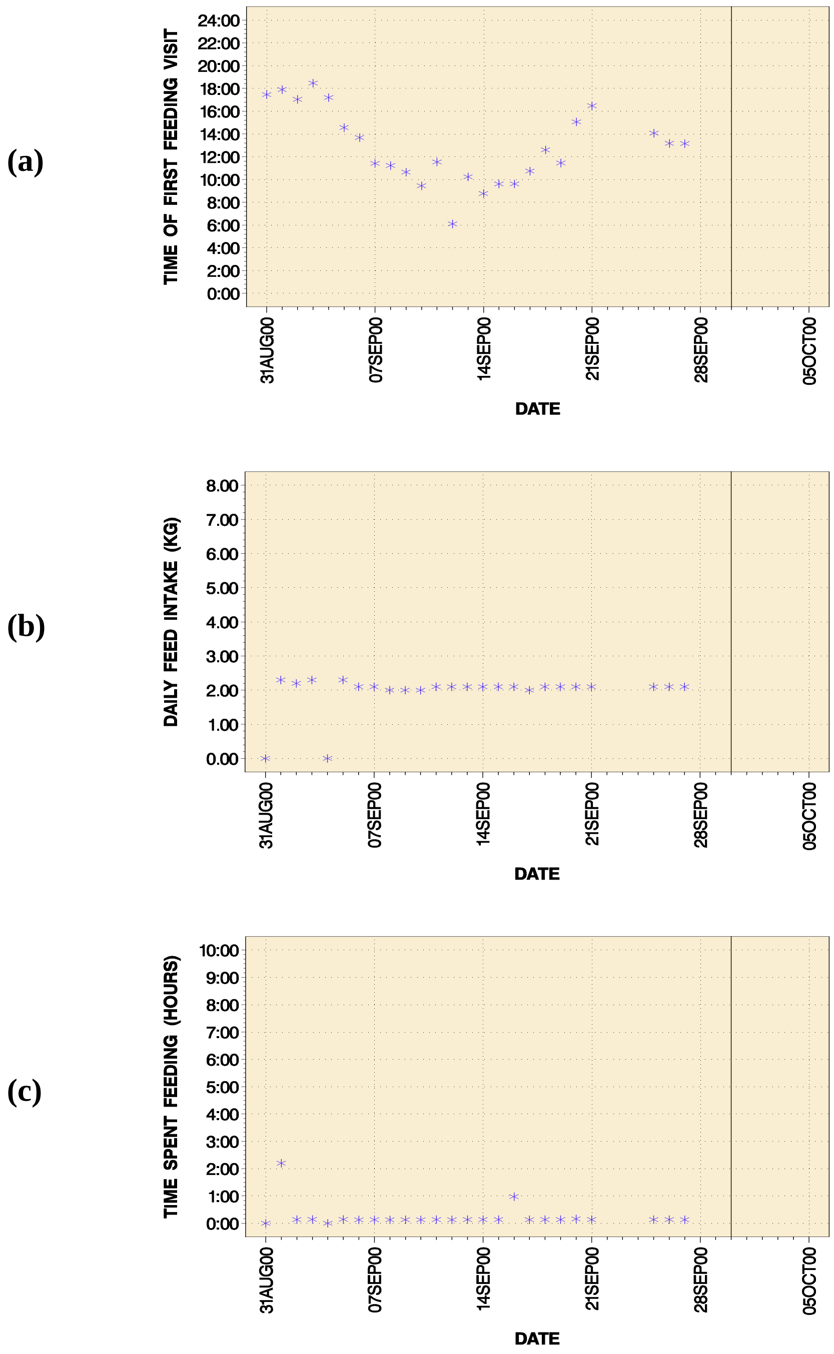

Figure A.10: Time series of sow 1116 showing time of first feeding visit (a), daily feed intake (b) and feeding time (c). The horisontal lines indicate date of mating.

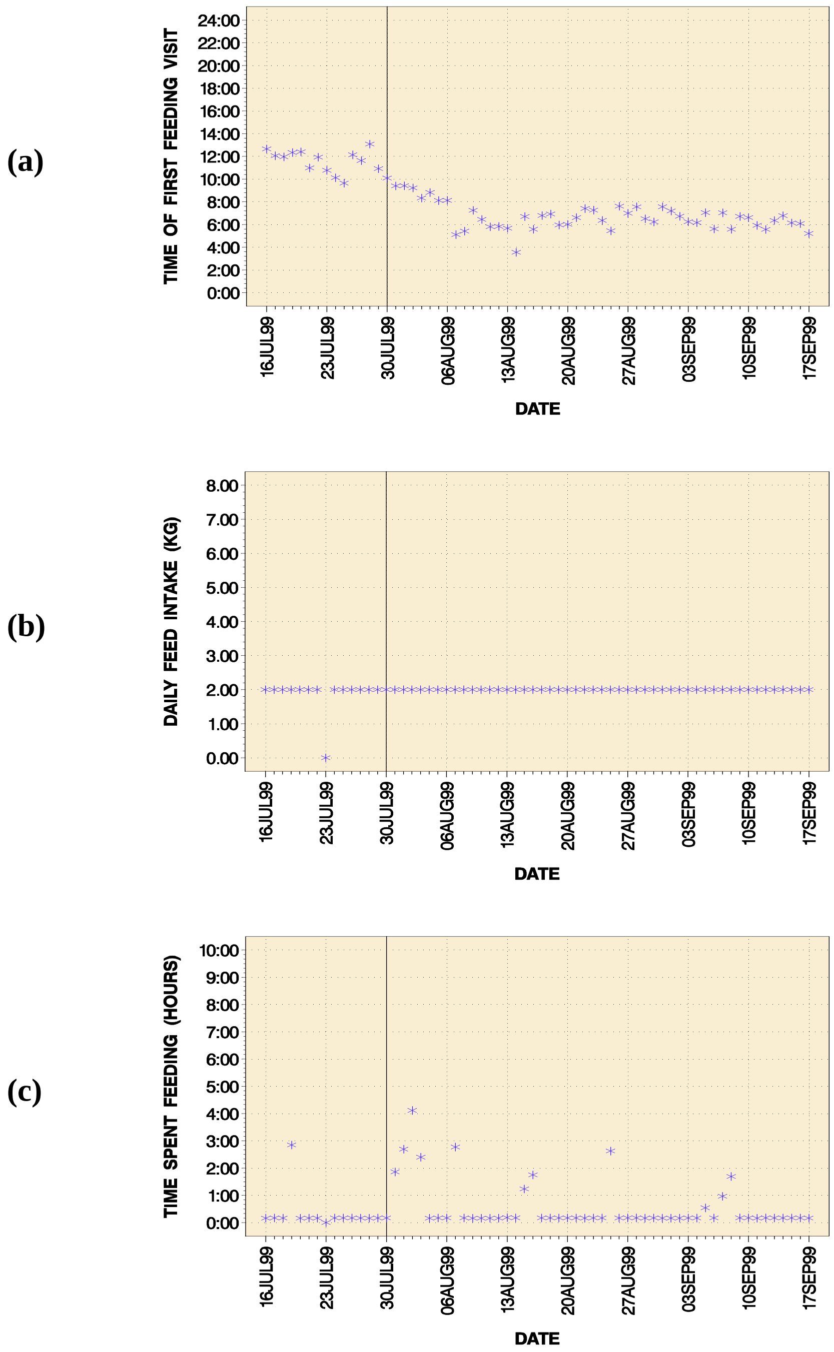

Figure A.11: Time series of sow 1155 showing time of first feeding visit (a), daily feed intake (b) and feeding time (c). The horisontal lines indicate date of mating.

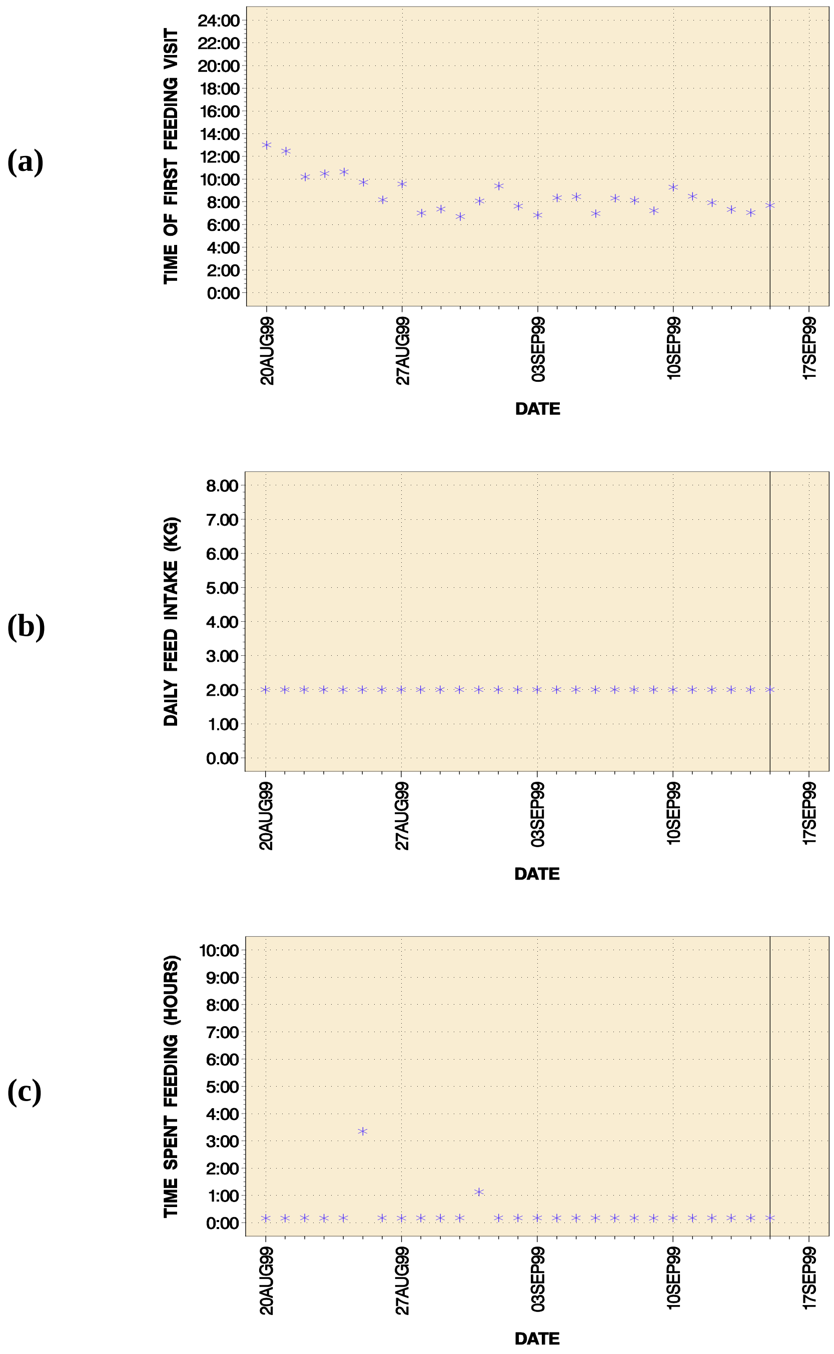

Figure A.12: Time series of sow 1167 showing time of first feeding visit (a), daily feed intake (b) and feeding time (c). The horisontal lines indicate date of mating.

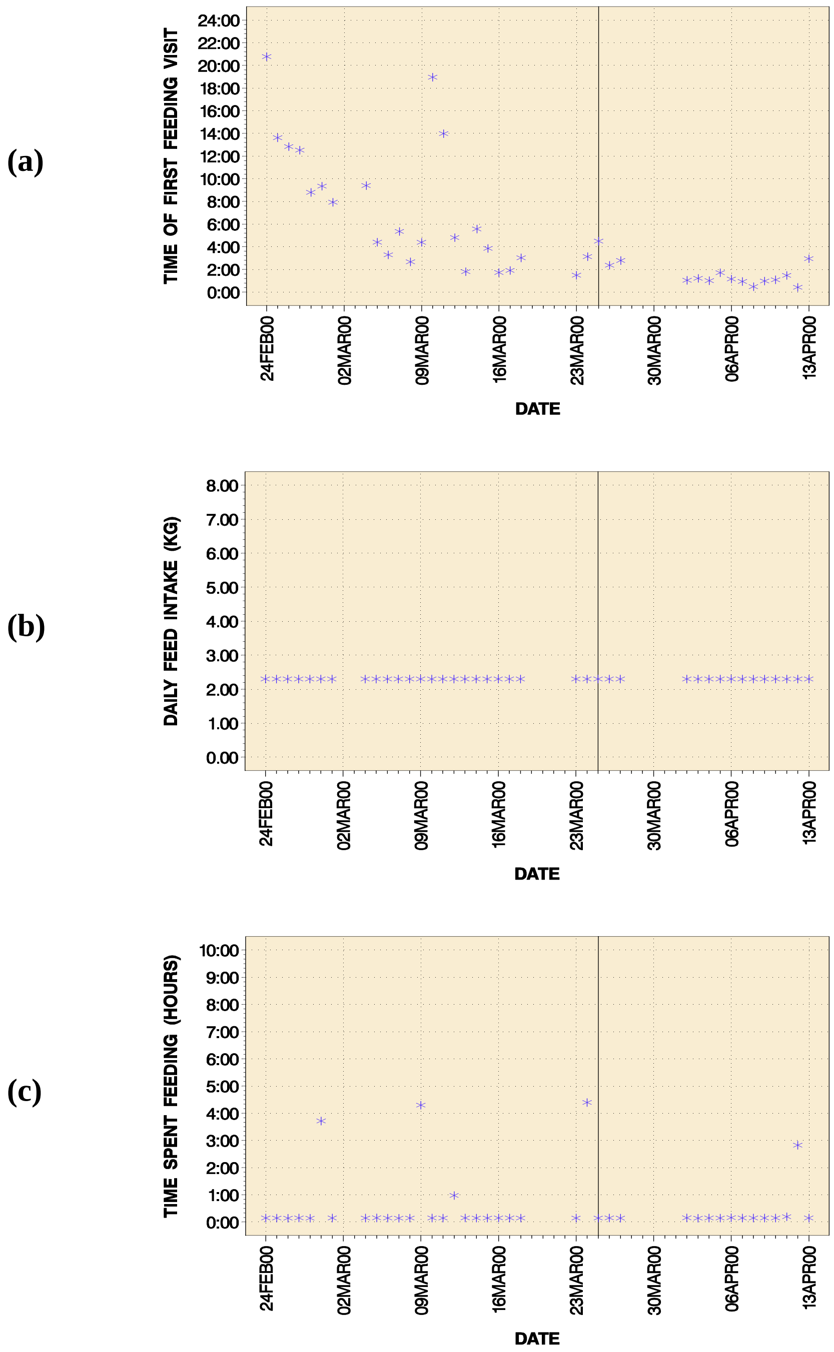

Figure A.13: Time series of sow 1227 showing time of first feeding visit (a), daily feed intake (b) and feeding time (c). The horisontal lines indicate date of mating.

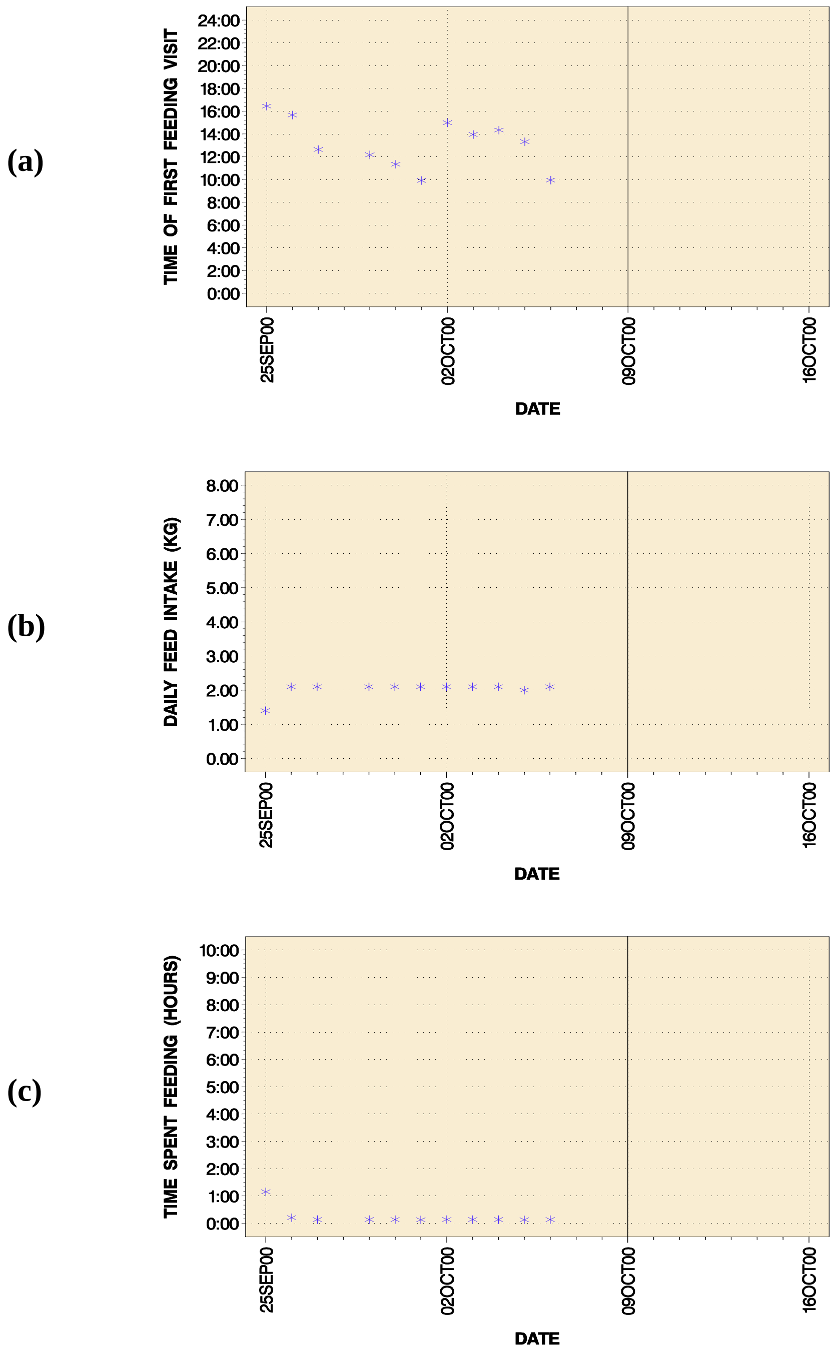

Figure A.14: Time series of sow 1288 showing time of first feeding visit (a), daily feed intake (b) and feeding time (c). The horisontal lines indicate date of mating.

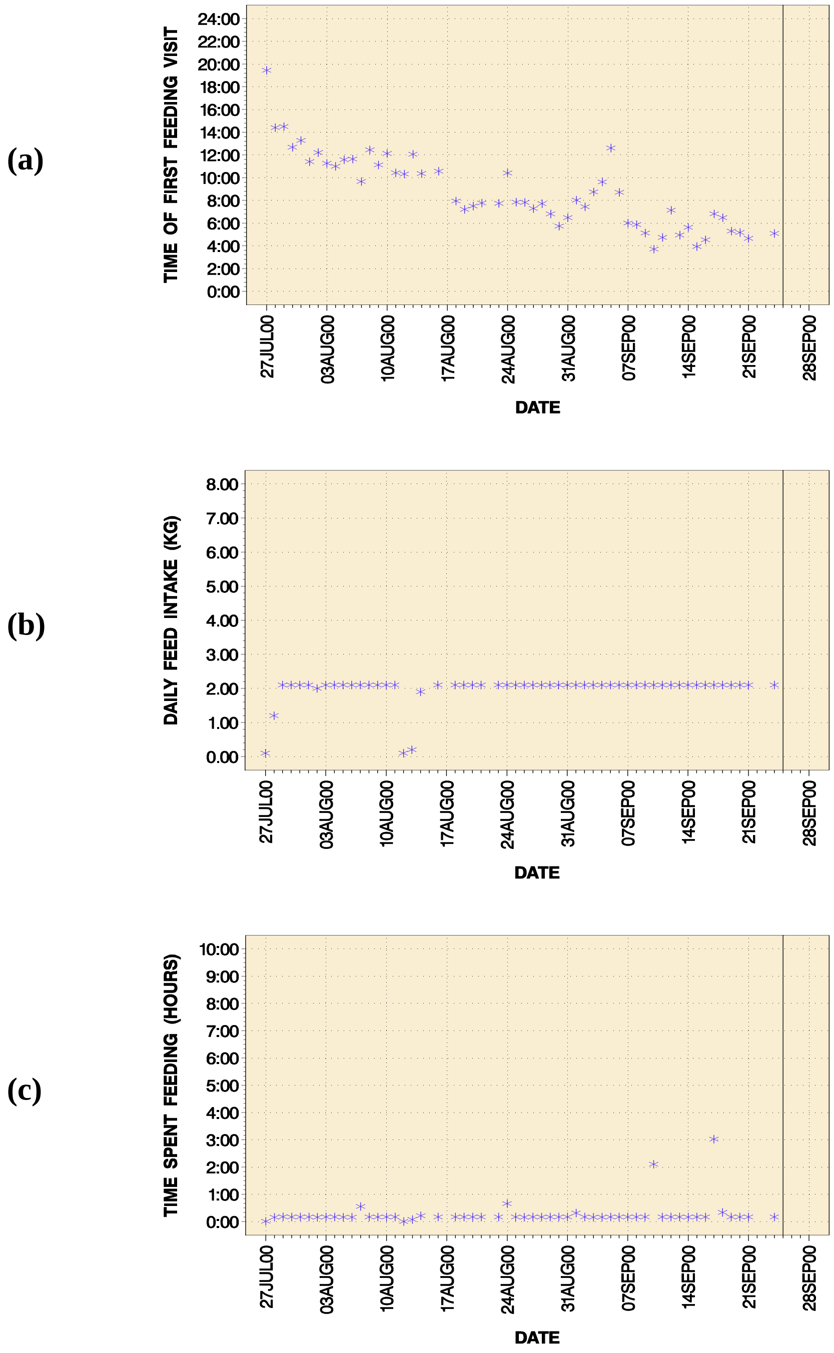

Figure A.15: Time series of sow 1343 showing time of first feeding visit (a), daily feed intake (b) and feeding time (c). The horisontal lines indicate date of mating.

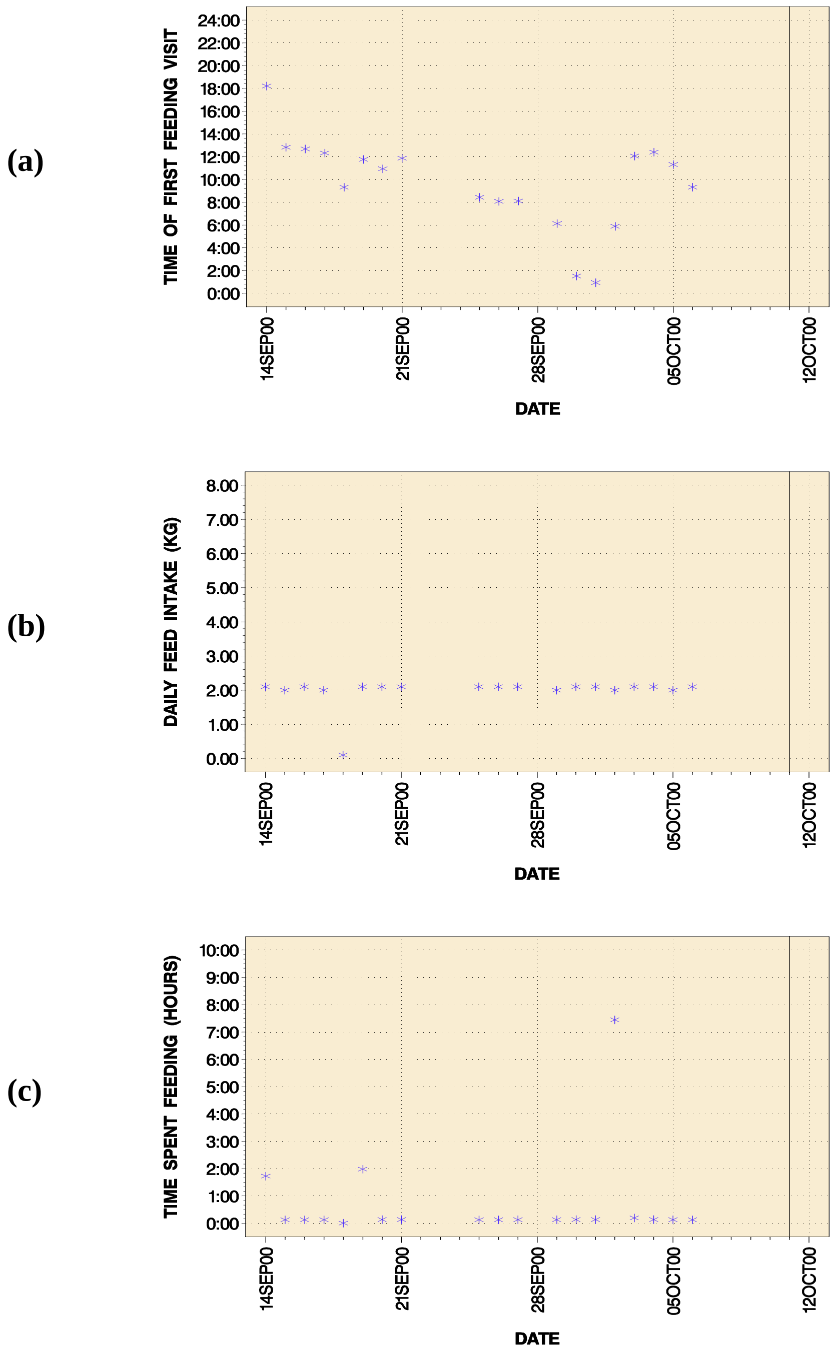

Figure A.16: Time series of sow 1401 showing time of first feeding visit (a), daily feed intake (b) and feeding time (c). The horisontal lines indicate date of mating.

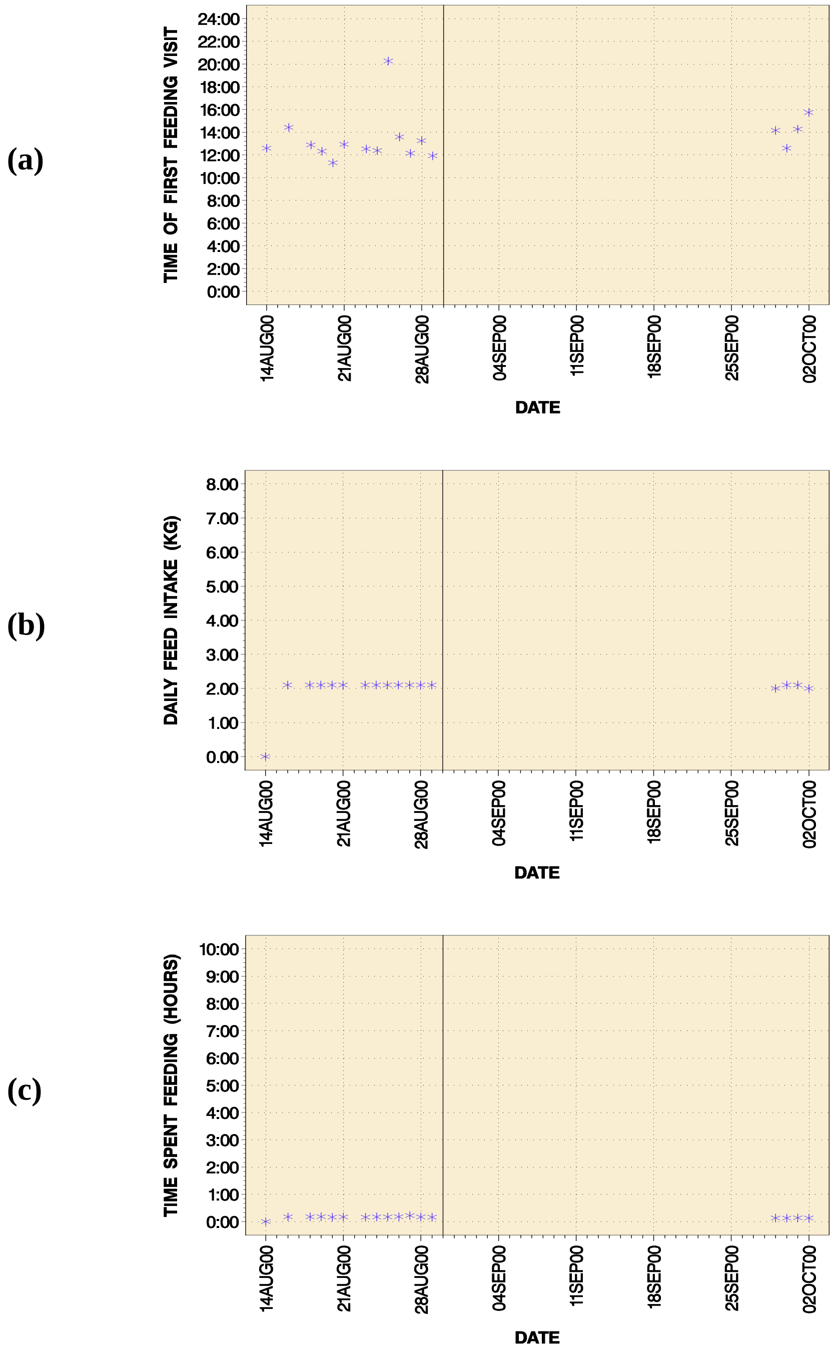

Figure A.17: Time series of sow 1490 showing time of first feeding visit (a), daily feed intake (b) and feeding time (c). The horisontal lines indicate date of mating.

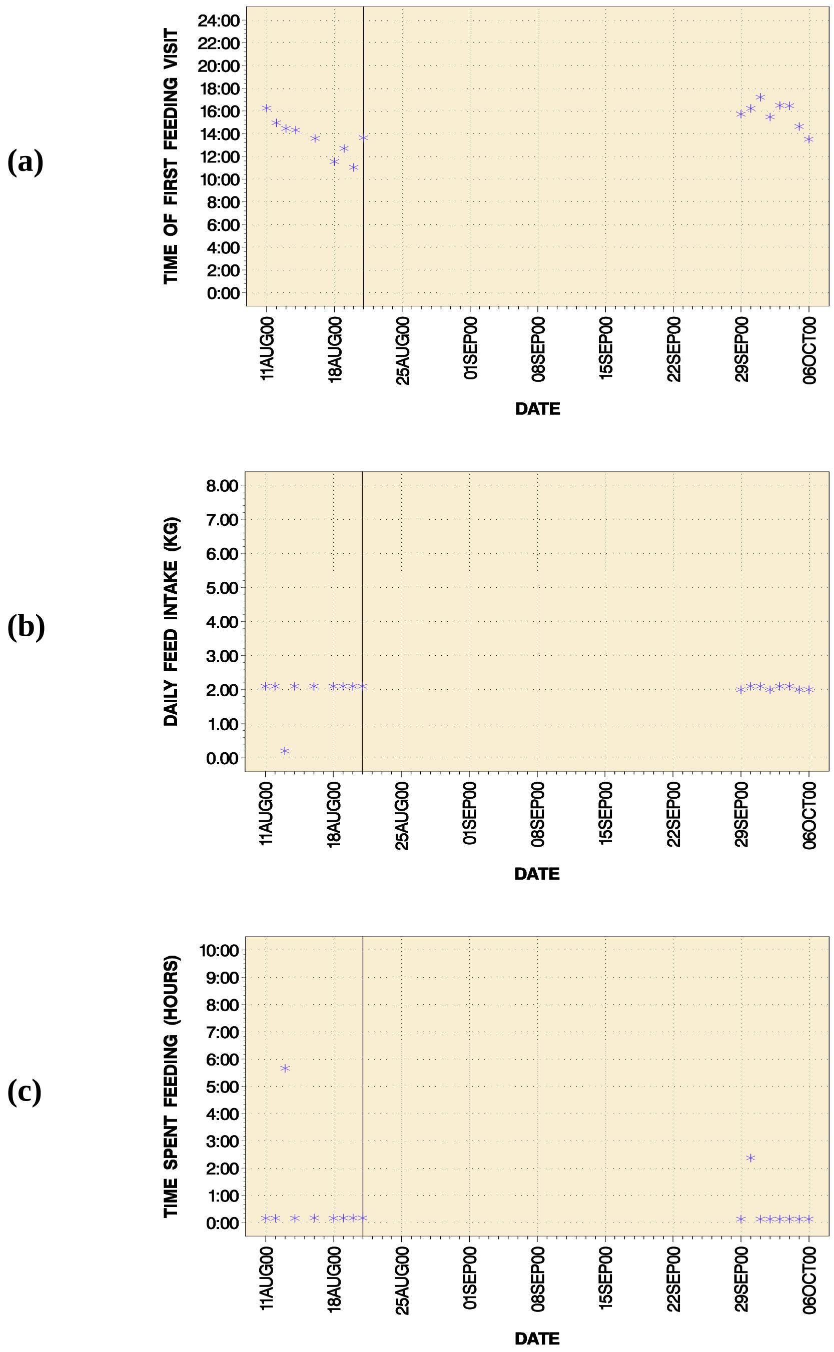

Figure A.18: Time series of sow 1513 showing time of first feeding visit (a), daily feed intake (b) and feeding time (c). The horisontal lines indicate date of mating.

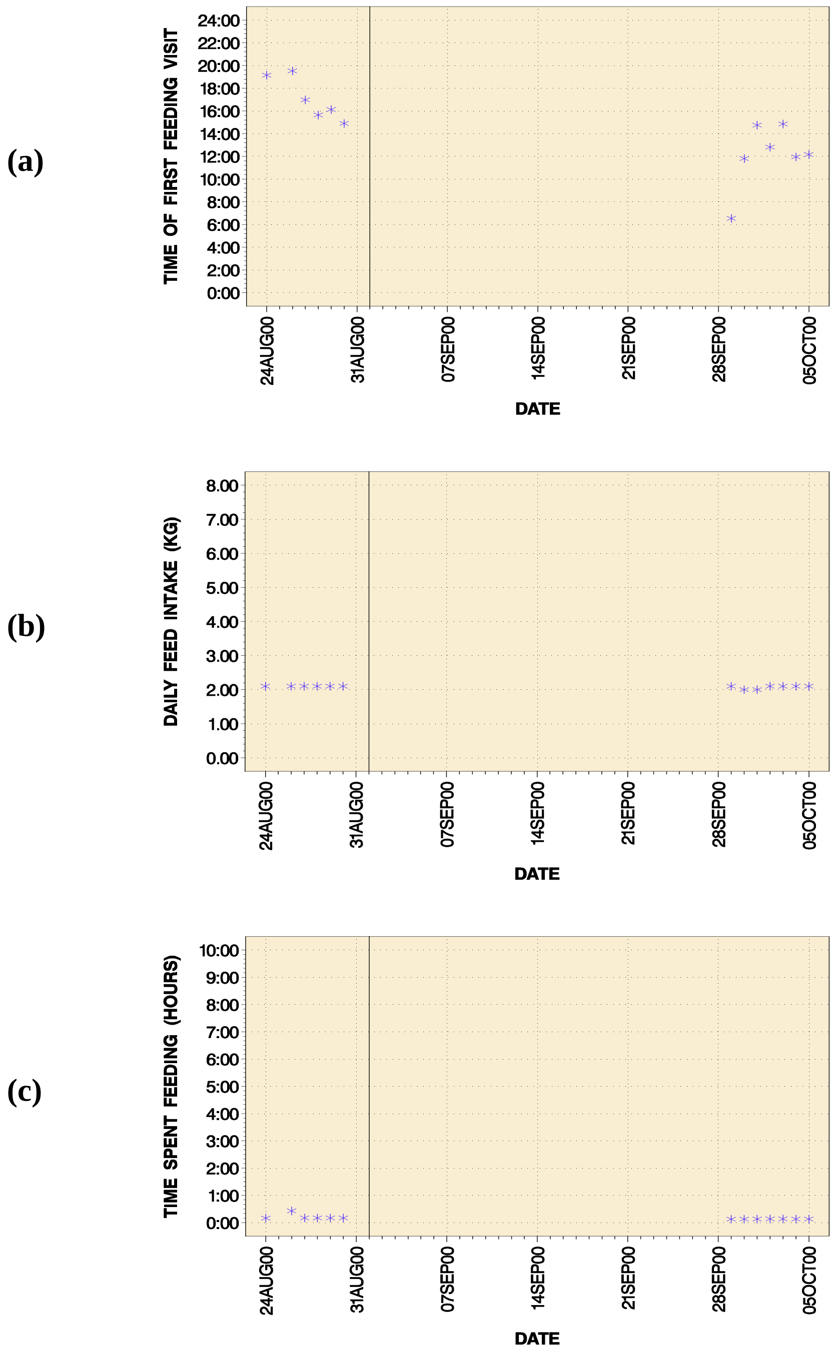

Figure A.19: Time series of sow 1529 showing time of first feeding visit (a), daily feed intake (b) and feeding time (c). The horisontal lines indicate date of mating.

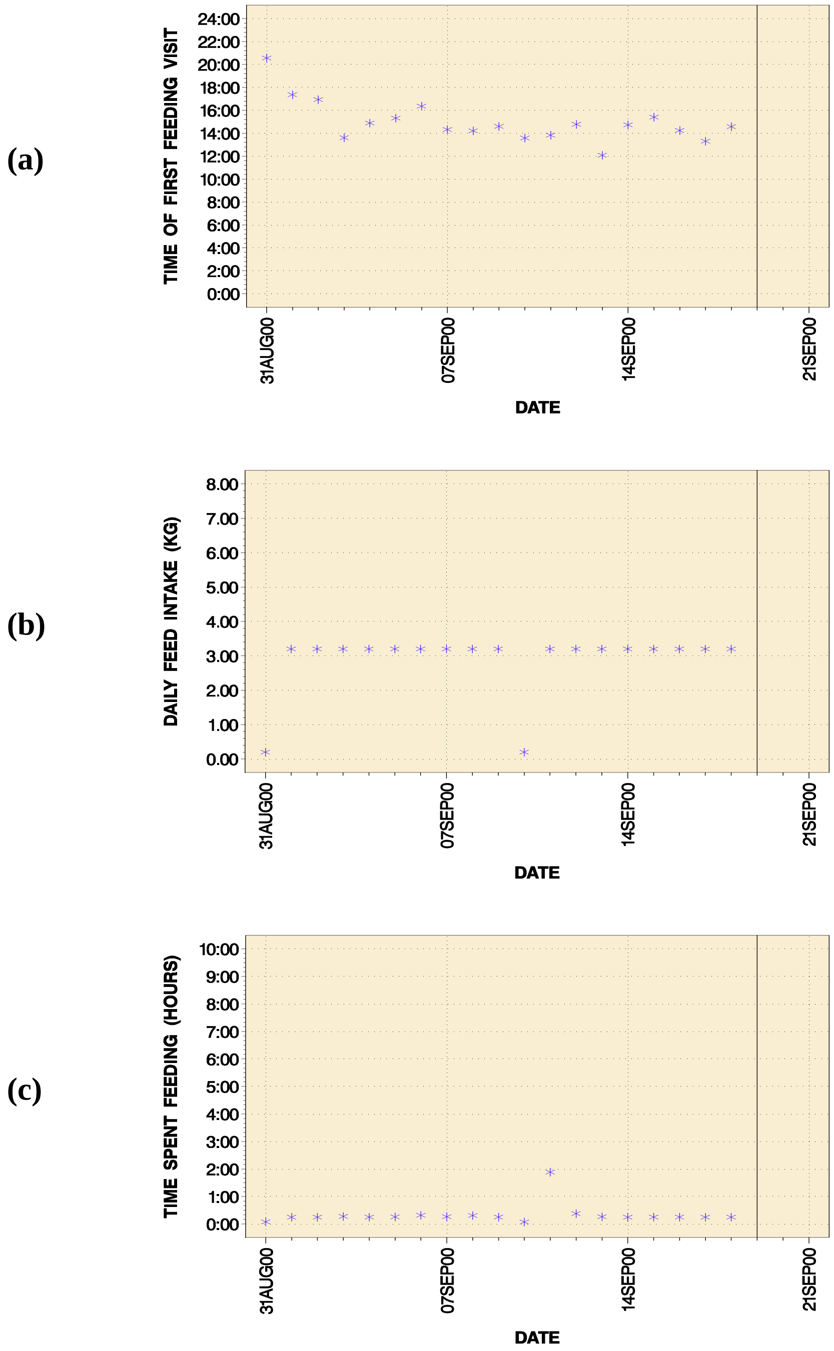

Figure A.20: Time series of sow 1545 showing time of first feeding visit (a), daily feed intake (b) and feeding time (c). The horisontal lines indicate date of mating.