MSc. Thesis Results

Effects of freestall barn layout on AMS efficiency of Dutch dairy farms with an automatic milking system

Daan Heurkens
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Abstract

When using an automatic milking system (AMS) efficiency is an important factor. AMS efficiency can be measured with several performance indicators ('milk yield per AMS', 'milk yield per minute', 'number of refusals', 'milking frequency' and 'free milk time'). The relationship between those performance indicators and barn layout has been subject of very few research. The objective of this research was to find freestall barn layout indicators which have an influence on performance indicators and thereby on AMS efficiency. Barn layouts of 127 Dutch dairy farms with a total of 240 AMS units were quantified in 30 layout variables to be analysed in this research. Performance data, provided by Lely Industries NV, were used from October 2014 up and until March 2015. Simple and multiple regression analyses were performed with a mixed model, whereby kg concentrates fed per cow was used as correction. For analyses with 'milk yield per AMS', 'number of refusals' and 'free milk time', farm effect was included as random factor. The results of the simple regression indicated that a straw area for separation and a split entry waiting area both had a positive effect on milk yield per AMS unit and milk yield per minute. Moreover, they decreased the free milk time. Furthermore, a separation possibility had a positive effect on milk yield per minute and milking frequency. The position of the concentrates stall positively affected the milk yield per AMS unit and reduced free milk time. The results for 'number of refusals' could not be interpreted with the current or with previous research. From this research can be concluded that barn layout indicators do affect performance indicators. These effects, however, are too small to estimate the performance indicators with a multiple regression analyses. In future research the barn layout indicators can be tested in an experimental design to get a better estimation of the effect of barn layout on the performance indicators.

Contents

1. Introduction

In 1992, the first automatic milking system (AMS) was sold commercially on the Dutch market (De Koning, 2010). Despite this early adaptation, large acceptance of this technology only came at the beginning of the 21st century. Over 3,400 dairy farms (19%) in the Netherlands were milking with an AMS in 2014 and this number is still increasing (Stichting Kwaliteitszorg Onderhoud Melkinstallaties, 2015). Using an AMS instead of a milking parlour requires a different approach in getting the cows to the milking machine. When using a milking parlour, the farmer brings his cows to the milking parlour two or three times a day. With an AMS, the cows have to go for milking by themselves (Scott et al., 2014). Each of these two types of milking impose different requirements on barn layout. The optimal utilization of barn layout indicators for AMS, such as feed bunk space, cubicles and stocking density, still has to be found (Halachmi et al., 2002).

Milk yield per AMS is an important measure for the efficiency of an AMS system. Taking the high investment costs per AMS unit into account, a higher milk yield per AMS unit can result in a better economic efficiency of the AMS. That is, the higher the milk yield per AMS unit, the more revenues per AMS unit are generated, the lower the capital costs per litre of milk produced (Sonck & Donkers, 1995; De Koning & Rodenburg, 2004). Optimal usage of the AMS unit can be achieved by optimizing performance indicators. For example, maximizing milk yield per minute spend in the AMS unit (Castro et al., 2012), improving milking frequency, and minimizing free milk time of an AMS unit (Dooren et al., 2004). Milking frequency improves the usage of the AMS unit because cows achieve a higher milk production per hour (Hogeveen et al., 2001). Furthermore, André et al. (2010) proved that an optimal milking frequency per cow leads to a higher milk yield per AMS unit. If the milk yield per minute spend in the AMS unit is increased, the visit of a cow to an AMS unit is more efficient. This indicator can be influenced negatively by stress, since cows that suffer from stress have a lower milk speed (Szentléleki et al., 2015). The free milk time is the time that the AMS unit is available for milking. If this time is used for milking additional cows or milking the same number of cows more frequently, AMS efficiency can be improved. In addition, the number of refusals, can be an indication for the willingness of the cows to come to the AMS system. If the number of refusals is relatively high, cows are visiting the AMS quite often, which may indicate that a farmer has to bring less cows to the AMS and thus saves time, and by doing so, making the AMS unit more efficient.

Considerable research has been done on the layout of barns with a conventional milking parlour. Tucker et al. (2004) found that cows spend more time lying down and less time standing in the cubicle with their front two hooves, with larger cubicles. But larger cubicles are more likely to get dirty (Tucker et al., 2004). The water trough capacity is of influence on the milk yield for higher parity cows. Naess et al. (2011) found that these cows had a higer milk yield with a water trough capacity of more than 8 cm per cow. Large water troughs with a large surface area are also responsible for an increased water consumption (Pinheiro Machado Filho et al., 2004; Dayane et al., 2006). The position of the water trough, on the other hand, has no influence on milk production, except for yields from primiparious cows. They have a lower milk yield when the water trough is located next to the wall, and they benefit from water troughs located in front of the first freestall row (Naess et al., 2011). The milk yield will increase when competition at the feed bunk is reduced. This can be achieved by increasing feed bunk space (DeVries & Keyserlingk, 2006; Deming et al., 2013). Naess et al. (2011) found that two or more dead end alleys will reduce milk yield.

Specific studies on AMS barn layout are mostly done on cow traffic. The distinction can be made between free, semi-forced and forced cow traffic (Bach et al., 2009; Hermans et al., 2003). Semi-forced cow traffic tends to be better for feeding area usage compared to forced cow traffic (Hermans et al., 2003). With forced cow traffic, eating behaviour became worse but 'voluntary' AMS visits improved compared to free cow traffic (Bach et al., 2009). Jacobs et al. (2012) described that gates and alleys positioned around the AMS may affect cow traffic and cow behaviour, which potentially affects the time the AMS is available for milking.

Previous research on performance indicators and barn layout in AMS freestall barns has often been limited to an experimental herd and barn design. This reflects a very specific situation in which only a few barn lay-out indicators are investigated. Moreover, a lot of research on barn layout in freestall barns is being done in combination with a milking parlour. Naess et al. (2011) compared the layout of 204 dairy freestall barns with the milk yield and calving interval of each parity. This study was focused on small farms (average: 42,7 cows per farm) that did not specifically use an AMS. In modern agriculture with large herd sizes and increasing adoption of AMS instead of milking parlours, these studies have become obsolete.

The current study compares the layout indicators of a large number of Dutch AMS barns with performance indicators. The results of the study will explain which aspects of barn layout improve AMS efficiency. This may help farmers and producers of automatic milking systems to design new and optimized freestall AMS barns likely to improve AMS efficiency.

2. Material and Methods

2.1. The Farms

The research was carried out in collaboration with Lely Industries NV (Maassluis, the Netherlands). Lely has six Dutch dealers (so-called 'Lely Centres'), which provided information from 182 farms located across the Netherlands. Information included location, farm size, year of installation, AMS type, and barn layout. To qualify for the current research, a farm should have started milking with an AMS in March 2014 at the latest, and they should have a freestall barn in combination with free cow traffic. The AMS units had to be, A3, A3N, or A4 version.

2.2. Observations on Barn Layout

The Lely Centres provided a barn layout of each farm. These layouts were retrieved in a .pdf, MS Word or a .dwg format. The .pdf and MS Word files were transformed into a .dwg file. These files were scaled to actual sizes (in mm) in AutoCAD. Layouts that could not be rescaled were excluded from further analyses (n=54).

Two experts on barn layout (N. Vreeburg, Vetvice, Megen, the Netherlands; E. Pijnappels, DLV, Uden, the Netherlands) were interviewed to determine 30 variables on which the drawings were measured (Table 2.1). For further information on the variables and classes see Table 3.1. Based on expert opinion, 22 variables were categorised; the remainder variables were considered continuous variables. Barns with cubicle rows not parallel to the feed bunk (n=1) were excluded from further analyses. This left 127 farms (and barn layouts) with a total of 240 AMS units for further analyses. All variables listed in Table 2.1 were measured on each barn to quantify the barn layout.

2.3. Performance Data

Lely Industries provided performance data. These data were collected from every AMS unit every month. Data consisted of five performance indicators: 'milk yield per AMS', 'milk yield per minute spend in the AMS unit', 'number of refusals', 'milking frequency' and 'free milk time of the AMS unit'. Data from farms with one single AMS units or where AMS units were the only one within a group of cows, were used for the statistical analyses on 'milking frequency'. In addition to these performance indicators, the amount of concentrates fed per AMS unit was also provided. For the current research, data from October 2014 up and until March 2015 were used. Since data were collected per month, six repeated measures were collected for each performance indicator.

Table 2.1. Independent barn layout variable names and descriptions as determined by two experts during a face-to-face interview. The type of variable (categorical or continuous) is also presented.

Number	Variable	Description of variable	Type of variable
1	Cubicle number per AMS	Number of cubicles per AMS unit	Continuous
2	Cubicle wall width	Width of cubicles next to the wall	Categorical
3	Cubicle wall length	Length of cubicles next to the wall	Categorical
4	Cubicle middle width	Width of cubicles not next to the wall	Categorical
5	Cubicle middle length	Length of cubicles not next to the wall	Categorical
6	Feed bunk space per cubicle	Length of feed bunk space per Cubicle	Continuous
7	Distance AMS to cubicle row	Distance from AMS unit to cubicles row	Continuous
8	Separation possibility	Possibility to automatically separate cows from the group	Categorical
9	Separation trough 2nd AMS unit	A cow needs to go through a 2nd AMS unit to reach the separation area	Categorical
10	Cubicles separation area	Number of cubicles in separation area	Categorical
11	Straw area	Presence of a straw area for separation cows	Categorical
12	Surface straw area	Surface of the straw area	Continuous
13	Split entry waiting area	Presence of a split entry waiting area (a waiting area in which cows can be locked without interrupting the voluntary visiting behaviour of other cows	Categorical
14	AMS type	Type of AMS Lely A3, A3N or A4	Categorical
15	AMS left / right	Left or right hand entrance to the AMS	Categorical
16	AMS length position	Length position of the AMS unit	Categorical
17	AMS width position	Width position of the AMS unit	Categorical
18	AMS alignment	Alignment of the AMS in the barn	Categorical
19	AMS per group	Number of AMS units per group	Categorical
20	Water trough distance to AMS	Water trough distance to AMS	Continuous
21	Walk way length	Maximum walking distance to AMS unit	Continuous
22	Walk way width at feed bunk	Width of the walkway next to the feed bunk	Categorical
23	Walk way width in middle	Width of the walkway between the Cubicle rows	Categorical
24	Walk way surface per cubicle	Total walk way surface per cubicle	Continuous
25	Crossover position	Number of cubicles between AMS unit and the first crossover (interruption in cubicle rows by walkway)	Categorical
26	Walk way dead ends	Number of alleys without crossovers at the end	Categorical
27	Concentrates stall length position	Length position of concentrates feeder	Categorical
28	Concentrates stall width position	Width position of concentrates feeder	Categorical
29	Concentrates stall occupation	Number of cubicles per concentrate feeder	Continuous
30	Barn model	Barn model expressed in cubicle rows feed bunk length	Categorical

2.4. Statistical Analyses

The aforementioned five performance indicators were included in the model as dependent variables (Table 2.2). ‘Milk yield per AMS’, ‘milk yield per minute spent in the AMS unit’ and ‘free milk time’ had normal distribution (Table 2.2) of the residuals, so they were analysed with a Linear Mixed Model (LMM). For these variables, data analyses were performed with a proc mixed procedure in SAS (version 9.3, SAS Institute Inc. , Cary, NC). The other two performance indicators (‘number of refusals' and 'milking frequency') had a Poisson distribution of the residuals (Table 2.2). These variables were analysed with the proc glimmix procedure with the option tech=nrridg to use the same optimization technique as is used with the proc mixed procedure (Littell et al., 2006). Repeated measures per month, for each AMS unit nested within farm, were included in the model. The option ddfm=kr is added to calculate the denominator degrees of freedom for a repeated measures model (Littell et al., 2006). To correct for different leg sizes between months (difference between first and second month is smaller than the difference between the first and sixth month), the option 'type=ar(1)' was added (Littell et al., 2006). The intra correlation coefficient (ICC) was analysed per dependent variable to determine if a random herd effect had to be added to the model. If the ICC was low, the total random variation was not dominated by the variance of the random farm effects (West et al., 2007), and thus, the random farm effect was not included in the model for the variables with a low ICC. Table 2.2 reports for each of the five dependent variables whether a random farm effect was included based on ICC. The analyses were performed for each of the five dependent variables. The amount of concentrates fed per cow was included as independent fixed effect in each of the models. So, the simple regression model for the dependent variables uses the following formula:

$$Y_j = \beta_0 + \beta_1 * \text{ concentrates fed}_j + \beta_2 * X_{1j} + \mu_{farm(j)} + \varepsilon_j \qquad [1]$$

Where Y_j = 'milk yield per day', 'milk yield per minute spent in the AMS unit', 'number of refusals', 'milking frequency' or 'free milk time of the AMS unit' for each AMS (j); β_0 = intercept; β_1= fixed effect of concentrates fed; β_2 = fixed effect of the independent variable X_{1j}, where each of the barn layout variables (Table 2.1) were introduced into the model one by one; $\mu_{farm(j)}$ = random effect on farm level for each AMS (according to Table 2.2) and ε_j = random effect for the jth AMS unit.

Table 2.2. Dependent variables in the research with their unit, distribution of residuals, ICC values and if the random herd effect is included in the model

Variable	**Unit**	**Distribution of residuals**	**ICC**	**Random herd effect included**
Milk yield per AMS	Litres / day	Normal	0.8360	Yes
Milk yield per minute	Litres / minute spend in the AMS unit	Normal	0.0028	No
Number of refusals	Per cow / day	Poisson	0.1807	Yes
Milking frequency	Per cow / day	Poisson	0.0133	No
Free milk time	% / day / AMS	Normal	0.7911	Yes

From the simple regression analysis, variables were selected to be included in the multiple regression model, on the basis of their significance level ($p<0.10$; (Dohoo et al., 2009)). The final model was constructed using a backward elimination procedure. The order of exclusion was determined by the significance level. The variable with the highest p-value was excluded first. This procedure was repeated till there were no variables left with a p-value > 0.05. The interaction between the amount of concentrates fed and the fixed effect were also tested in the model. The final model was expressed as:

$$Y_{kj} = \beta_0 + \beta_1 * \text{concentrates fed}_j + \beta_2 * (X_{1j}) + \beta_k * (X_{kj}) + \beta_3 * \text{concentrates fed}_j * X_{1j} + \beta_k * \text{concentrates fed}_j * X_{kj} + \mu_{farm(j)} + \varepsilon_i \quad [2]$$

Where the parameters in equation [2] have the same meaning as those in equation [1], and where $\beta_2 * (X_{1j}) + \beta_k * (X_{kj})$ represents the fixed effect of the included variables X_{1j} ... X_{kj}, and where $\beta_3 *$ concentrates $\text{fed}_j * X_{1j} + \beta_k *$ concentrates $\text{fed}_j * X_{kj}$ represents the interaction between concentrates fed and the included variables X_{1j} ... X_{kj}. In case that only the interaction effect of a variable with kg concentrates fed was significant in the final model, the main effect of that variable is reintroduced in the model. This made it possible to make an interpretation of the interaction effect. All statistical analyses and figures produced were done using SAS (version 9.3, SAS Institute Inc., Cary, NC).

3. Results

Boxplots and scatterplots were created to provide insight in the data used for the research. Some of the independent variables were missing for some barn layouts, and thus, the mean and standard deviation of the dependent variable can differ per independent variable. Figures A1, A4, A7, A10 and A13 show one boxplot for each independent variable with respect to the dependent variable. In addition, Figures A2, A3 (milk yield per AMS), A5, A6 (milk yield per minute), A8, A9 (number of refusals), A11, A12 (milking frequency), A14 and A15 (free milk time) show scatterplots of independent continuous variables with respect to the dependent variable. These plots show the distribution of the observations for each variable. Furthermore, in this chapter results of the simple regression analyses and of the multiple regression analyses are provided per dependent variable.

3.1. Milk yield per AMS

On average, the milk yield per AMS was 1,452.3 litres per day (range: 462.9-2231.8, standard deviation 293.3 litres). A maximum of 1,264 observations were used in the simple regression analysis.

Simple regression analysis

Table 3.1 summarizes significance effects of the independent variables on ‘milk yield per AMS’. The following variables had a significant ($p<0.10$) effect on the milk yield per AMS: an increased number of cubicles per AMS had a small but statistically significantly negative effect. Separation through a second AMS unit, presence a straw area, the surface of the straw area and a split entry waiting area all individually had a positive significant effect. However, if the AMS was positioned in the middle width position, it had a negative effect compared to a situation in which it is positioned on the right side. With only one AMS in a group the milk yield per AMS was significantly lower than with three AMS units in a group. Furthermore, the milk yield was lower when there were more than 15 cubicles between the AMS unit and the first crossover. When the concentrates stall was positioned in the middle of the cubicles row or at the feed bunk walkway, the milk yield per AMS was significantly higher compared to a situation without a concentrates stall.

Table 3.1. Effect of barn layout variables on milk yield per AMS unit (simple regression procedure in which one independent variable is corrected for kg concentrates / cow and the random herd effect)

Variable	Class	n	Estimate	SE	DF	t Value	P
Cubicle number per AMS	Continuous[1]	1264	-4.9478	1.2245	202	-4.04	<.0001
Cubicle wall width	<=1,15 m	720	166.9400	103.4100	138	1.6100	0.1087
	>1,15 m		0.0000	.	.	.	.
Cubicle wall length	<=2,65 m	696	82.3784	53.6690	130	1.5300	0.1272
	>2,65 m		0.0000	.	.	.	.
Cubicle middle width	<=1,15 m	1234	41.4137	77.8562	248	0.5300	0.5953
	>1,15 m		0.0000	.	.	.	.
Cubicle middle length	<=2,35 m	1186	-57.5102	39.8313	238	-1.4400	0.1501
	>2,35 m		0.0000	.	.	.	.
Feed bunk space per cubicle	Continuous	1240	-0.1241	0.1305	246	-0.9500	0.3427
Distance AMS to cubicles row	Continuous	1258	0.0290	0.0240	229	1.2100	0.2281
Separation possibility	Yes	1264	39.6919	71.0736	248	0.5600	0.5770
	No		0.0000	.	.	.	.
Separation through 2nd AMS unit	Yes	1222	159.9400	38.0931	253	4.2000	<.0001
	No		0.0000	.	.	.	.
Cubicle number separation area	<=4	1126	48.3913	38.5937	221	1.2500	0.2112
	>4		0.0000	.	.	.	.
Straw area	Yes	1264	114.93	25.344	214	4.53	<.0001
	No		0.0000	.	.	.	.
Surface straw area	Continuous	1264	1.7595	0.3134	217	5.61	<.0001
Split entry waiting area	Yes	1264	135.4700	40.1932	263	3.3700	0.0009
	No		0.0000	.	.	.	.
AMS Type	A3	1264	-150.2600	143.3700	104	-1.0500	0.2970
	A4		-14.0535	66.1005	108	-0.2100	0.8320
	A3N		0.0000	.	.	.	.
AMS left / right	Left	1264	-11.2334	17.9234	161	-0.6300	0.5317
	Right		0.0000	.	.	.	.
AMS length position	Front	1264	-134.3100	120.4500	150	-1.1200	0.2666
	Middle		-65.8724	157.9000	211	-0.4200	0.6770
	End		0.0000	.	.	.	.
AMS width position	Left	1264	11.0735	16.9209	145	0.6500	0.5139
	Middle		-75.7917	31.1386	214	-2.4300	0.0158
	Right		0.0000	.	.	.	.
AMS alignment	Right-angled on Feed bunk	1264	112.1800	72.6685	240	1.5400	0.1240
	Parallel to feed bunk front at feed bunk		129.2000	92.0917	188	1.4000	0.1623
	Parallel to feed bunk front not at feed bunk		0.0000	.	.	.	.
AMS per group	1	1264	-377.39	130.68	111	-2.89	0.0047
	2		-162.59	129.02	106	-1.26	0.2104
	3		0	.	.	.	.
Water trough distance to AMS	Continuous	921	0.0034	0.0092	183	0.3700	0.7129
Walk way length	Continuous	1252	0.0032	0.0021	212	1.5300	0.1287
Walk way width at feed bunk	<=3,5 m	1084	-11.3994	41.6168	218	-0.2700	0.7844
	>3,5 m		0.0000	.	.	.	.

Variable (continued)	Class	n	Estimate	SE	DF	t Value	P
Walk way width in middle	<=2,5 m	1174	-4.4394	41.5825	236	-0.1100	0.9151
	>2,5 m		0.0000	.	.	.	.
Walk way surface / cubicle	Continuous	1264	16.1827	16.0897	234	1.01	0.3156
Crossover position	<= 15 cubicles	1222	-82.5088	39.6021	246	-2.0800	0.0382
	> 15 cubicles		0.0000	.	.	.	.
Walk way dead ends	0	1264	8.5684	70.1211	254	0.1200	0.9028
	1		20.9765	87.6129	252	0.2400	0.8110
	>1		0.0000	.	.	.	.
Concentrates stall length position	Begin cubicles row	1264	46.3565	94.4994	258	0.49	0.6242
	Middle cubicles row		289.87	42.3432	251	6.85	<.0001
	End cubicles row		83.9949	105.74	244	0.79	0.4278
	Not present		0	.	.	.	.
Concentrates stall width position	At feed bunk walkway	1264	292.47	40.4749	259	7.23	<.0001
	Middle row		43.732	61.787	254	0.71	0.4797
	Both		234.45	129.71	104	1.81	0.0736
	Not present		0	.	.	.	.
Concentrates stall occupation	Continuous	471	1.7699	1.1869	52	1.4900	0.1419
Barn model	<= 2 cubicle rows per feed bunk length	1018	-57.7732	54.2993	196	-1.0600	0.2886
	>2 cubicle rows per feed bunk length		0.0000	.	.	.	.

[1] Mean cubicle number per AMS 60.5 ± 9.9, range 39 – 126; feed bunk space per cubicle 590.5 ± 134.8 mm, range 69.6 – 990.6; distance AMS to cubicles row 4904.3 ± 912.2 mm, range 2651 – 8077; surface straw area 31.8 ± 40.8 m^2, range 0 – 147.5; water trough distance to AMS 5083.9 ± 2638 mm, range 1812 – 20132; walk way length 42229.9 ± 11328 mm, range 23604 – 88642; walk way surface per cubicle 4.6 ± 1.0 m^2, range 0 – 7.5; concentrates stall occupation 86.8 ± 28.7 cubicles /stall, range 23.8 - 138

Multiple regression analysis

The results of the multiple regression analysis of milk yield per AMS are presented in Table 3.2. Separation through a second AMS unit had a negative effect on the milk yield per AMS, which is a different result compared to the simple regression analysis. This means that in combination with all other variables presented in Table 3.2, the effect of separation through a second AMS unit had a negative effect, whereas it had a positive effect if it was the only independent variable in the simple regression. The same goes for the split entry waiting area. Moreover, the split entry waiting area had a positive interaction effect, which means that for every kg of concentrates fed, the effect of a split entry waiting area increases by 73.56 (if all other variables are held constant). If an AMS unit was positioned in the middle, when looking at the width position, the main effect was strongly negative compared to one on the right side. However, the interaction effect with kg concentrates / cow of the middle position was positive. In addition, two AMS units per group showed the same pattern, and had a strong negative main effect compared to three AMS units per group. On the other hand, the interaction effect of two AMS units per group was positive. When looking at the position of a concentrates stall, one at the feed bunk walkway had a positive effect on the milk yield per AMS unit compared to a situation in which none was present. Furthermore, the interaction between kg concentrates / cow and straw area showed a positive effect when a straw area was present.

However, if the main effect of a straw area was returned in the model, the effect of both the main and the interaction effect were not significant.

Table 3.2. Effect of barn layout variables on milk yield per AMS unit (multiple regression procedure in which all selected independent variables are corrected for kg concentrates / cow and the random herd effect n=1180)

Effect	**Class**	**Estimate**	**SE**	**DF**	**t Value**	**P**
Intercept		1351.4700	165.8000	197.1	8.15	<.0001
Kg Concentrates / Cow	Continuous	24.4937	34.5682	987.4	0.71	0.4788
Straw area	Yes	-2.1820	44.3766	337.6	-0.05	0.9608
	No	0.0000	.	.	.	.
Separation through 2nd AMS unit	Yes	111.4900	40.9641	274.8	2.72	0.0069
	No	0.0000	.	.	.	.
Split entry waiting area	Yes	-128.3300	51.9714	341.3	-2.47	0.0140
	No	0.0000	.	.	.	.
AMS Width position	Left	2.3917	43.4961	260.1	0.05	0.9562
	Middle	-265.5800	63.1787	263.3	-4.20	<.0001
	Right	0.0000	.	.	.	.
AMS per group	1	-175.8300	175.7900	220.9	-1.00	0.3183
	2	-683.6000	168.0600	193.9	-4.07	<.0001
	3	0.0000	.	.	.	.
Concentrates stall Width position	At feedbunk walkway	171.0100	36.0113	254.2	4.75	<.0001
	Middle walkway	-18.1760	54.7715	269.0	-0.33	0.7403
	Both	73.8778	153.6400	96.1	0.48	0.6317
	Not present	0.0000	.	.	.	.
Kg Concentrates / Cow*Straw area	Yes	17.1380	11.8781	401.3	1.44	0.1498
	No	0.0000	.	.	.	.
Kg Concentrates / Cow*Split entry waiting area	Yes	73.5625	13.8831	603.9	5.30	<.0001
	No	0.0000	.	.	.	.
Kg Concentrates / Cow*AMS Width position	Left	4.2093	14.0865	271.9	0.30	0.7653
	Middle	105.3100	19.1357	303.6	5.50	<.0001
	Right	0.0000	.	.	.	.
Kg Concentrates / Cow*AMS per group	1	-13.5035	35.8707	1090.0	-0.38	0.7067
	2	174.9400	35.9932	1102.0	4.86	<.0001
	3	0.0000	.	.	.	.
Random effects						
Farm		84366.00	12606.00			
Month		0.56	0.03			
Random error		9677.40	649.30			

3.2. Milk yield per minute

On average, the milk yield per minute was 1.5 litres (range: 1.0-2.0, standard deviation 0.2 litres). A maximum of 1,264 observations were used in the simple regression analysis.

Simple regression analysis

The results of the simple regression analysis (Table 3.3) show that the following variables had a significant ($p<0.10$) effect on milk yield per minute: the distance from the AMS unit to the cubicles row had a very small effect. A straw area, the surface of the straw area and a split entry waiting area, all individually showed a significant positive effect on the milk yield per minute. Furthermore, an AMS of type A4 had a lower milk yield per minute than one of type A3N. When looking at the length position of the AMS, if it was placed in the front or middle position of the barn, there was a negative effect on milk yield per minute. On the other hand, an AMS, which is positioned right-angled on the feed bunk, had a positive effect. If the number of cubicles between the AMS unit and the first crossover was less than 15, there was a negative effect. In contrast, one walkway dead end gave a higher milk yield per minute compared to multiple dead ends. Finally, a high concentrates stall occupation and a barn model with one or two cubicle rows per feed bunk length both had a negative effect on milk yield per minute.

Table 3.3. Effect of barn layout variables on milk yield per minute (simple regression procedure in which one independent variable is corrected for kg concentrates / cow)

Variable	Class	n	Estimate	SE	DF	t Value	P
Cubicle number per AMS	Continuous[1]	1264	-0.0018	0.0011	215	-1.65	0.1003
Cubicle wall width	<=1,15 m	720	-0.0356	0.0501	121	-0.71	0.4787
	>1,15 m		0.0000	.	.	.	.
Cubicle wall length	<=2,65 m	696	0.0113	0.0298	117	0.38	0.7060
	>2,65 m		0.0000	.	.	.	.
Cubicle middle width	<=1,15 m	1234	0.0029	0.0427	207	0.07	0.9460
	>1,15 m		0.0000	.	.	.	.
Cubicle middle length	<=2,35 m	1186	-0.0232	0.0261	206	-0.89	0.3751
	>2,35 m		0.0000	.	.	.	.
Feed bunk space per cubicle	Continuous	1240	-0.0001	0.0001	208	-0.98	0.3296
Distance AMS to cubicles row	Continuous	1258	0.0000	0.0000	212	1.81	0.0719
Separation possibility	Yes	1264	0.1086	0.0448	213	2.42	0.0162
	No		0.0000	.	.	.	.
Separation through 2nd AMS unit	Yes	1222	0.0217	0.0236	220	0.92	0.3605
	No		0.0000	.	.	.	.
Cubicle number separation area	<=4	1126	0.0136	0.0252	192	0.54	0.5896
	>4		0.0000	.	.	.	.
Straw area	Yes	1264	0.0625	0.0206	213	3.04	0.0027
	No		0.0000	.	.	.	.
Surface straw area	Continuous	1264	0.0005	0.0003	212	1.89	0.0606

Variable (continued)	Class	n	Estimate	SE	DF	t Value	P
Split entry waiting area	Yes	1264	0.0569	0.0215	213	2.64	0.0088
	No		0.0000	.	.	.	.
AMS Type	A3	1264	-0.0149	0.0512	212	-0.29	0.7707
	A4		-0.0509	0.0260	214	-1.96	0.0514
	A3N		0.0000	.	.	.	.
AMS left / right	Left	1264	0.0041	0.0210	212	0.20	0.8442
	Right		0.0000	.	.	.	.
AMS length position	Front	1264	-0.3003	0.1520	211	-1.98	0.0495
	Middle		-0.3303	0.1621	211	-2.04	0.0428
	End		0.0000	.	.	.	.
AMS width position	Left	1264	-0.0017	0.0257	212	-0.07	0.9479
	Middle		0.0259	0.0268	234	0.97	0.3343
	Right		0.0000	.	.	.	.
AMS alignment	Right-angled on Feed bunk	1264	0.1422	0.0488	213	2.92	0.0039
	Parallel to feed bunk front at feed bunk		0.1104	0.0888	212	1.24	0.2154
	Parallel to feed bunk front not at feed bunk		0.0000	.	.	.	.
AMS per group	1	1264	-0.0511	0.0461	233	-1.11	0.2693
	2		-0.0574	0.0429	212	-1.34	0.1823
	3		0.0000	.	.	.	.
Water trough distance to AMS	Continuous	921	0.0000	0.0000	154	-0.69	0.4931
Walk way length	Continuous	1252	0.0000	0.0000	0	.	.
Walk way width at feed bunk	<=3,5 m	1084	-0.0322	0.0250	184	-1.29	0.1979
	>3,5 m		0.0000	.	.	.	.
Walk way width in middle	<=2,5 m	1174	-0.0142	0.0254	202	-0.56	0.5765
	>2,5 m		0.0000	.	.	.	.
Walk way surface / cubicle	Continuous	1264	0.0118	0.0106	213	1.11	0.2676
Crossover position	<= 15 cubicles	1222	-0.0496	0.0217	205	-2.29	0.0230
	> 15 cubicles		0.0000	.	.	.	.
Walk way dead ends	0	1264	0.0300	0.0396	213	0.76	0.4504
	1		0.1027	0.0508	212	2.02	0.0446
	>1		0.0000	.	.	.	.
Concentrates stall length position	Begin cubicles row	1264	0.0693	0.0554	211	1.25	0.2121
	Middle cubicles row		0.0208	0.0230	212	0.90	0.3676
	End cubicles row		-0.1035	0.0771	210	-1.34	0.1807
	Not present		0.0000	.	.	.	.
Concentrates stall width position	At feed bunk walkway	1264	0.0366	0.0270	211	1.35	0.1769
	Middle row		0.0063	0.0339	211	0.19	0.8526
	Both		-0.0196	0.0481	213	-0.41	0.6838
	Not present		0.0000	.	.	.	.
Concentrates stall occupation	Continuous	471	-0.0011	0.0005	83.6	-2.15	0.0344
Barn model	<= 2 cubicle rows per feed bunk length	1018	-0.0483	0.0274	184	-1.77	0.0792
	>2 cubicle rows per feed bunk length		0.0000	.	.	.	.

[1] Mean cubicle number per AMS 60.5 ± 9.9, range 39 – 126; feed bunk space per cubicle 590.5 ± 134.8 mm, range 69.6 – 990.6; distance AMS to cubicles row 4904.3 ± 912.2 mm, range 2651 – 8077; surface straw area 31.8 ± 40.8 m^2, range 0 – 147.5; water trough distance to AMS 5083.9 ± 2638 mm, range 1812 – 20132; walk way length 42229.9 ± 11328 mm, range 23604 – 88642; walk way surface per cubicle 4.6 ± 1.0 m^2, range 0 – 7.5; concentrates stall occupation 86.8 ± 28.7 cubicles /stall, range 23.8 - 138

Multiple regression analysis

The results of the multiple regression analysis on milk yield per minute are presented in Table 3.4. The results show that AMS units of type A3 and A4 both had a negative main effect compared to the A3N type. However, the interaction with kg concentrates / cow was positive for the A3 type, which means that the effect of this type increased for every kg of concentrates fed. Furthermore, the interaction of kg concentrates / cow with concentrates stall occupation had a very small negative effect on the milk yield per minute. However, when the main effect was returned in the model, both the main and interaction effect of concentrates stall occupation were not significant.

Table 3.4. Effect of barn layout variables on milk yield per minute (multiple regression procedure in which all selected independent variables are corrected for kg concentrates / cow n=387)

Effect	Class	Estimate	SE	DF	t Value	P
Intercept		1.6649	0.1395	252.0	11.93	<.0001
Kg Concentrates / Cow	Continuous	0.0031	0.0350	350.0	0.09	0.9293
AMS Type	A3	-0.6187	0.2648	379.0	-2.34	0.0200
	A4	-0.2211	0.0919	197.0	-2.41	0.0170
	A3N	0.0000	.	.	.	.
Concentrates stall occupation	Continuous	0.0000	0.0013	337.0	0.01	0.9904
Kg Concentrates / Cow * AMS type	A3	0.2126	0.0902	326.0	2.36	0.0190
	A4	0.0437	0.0235	262.0	1.86	0.0636
	A3N	0.0000	.	.	.	.
Kg Concentrates / Cow * Concentrates stall occupation	Continuous	-0.0005	0.0004	371.0	-1.19	0.2362
Random effects						
Month		0.9322	0.0116			<.0001
Random error		0.0178	0.0028			<.0001

3.3. Number of refusals

On average, the number of refusals was 3.1 times per day per cow (range: 0.7-11.2, standard deviation 1.6 times a day). A maximum of 1,264 observations were used in the simple regression analysis.

Simple regression analysis

Table 3.5 shows that the following variables had a significant (p<0.10) effect on the number of refusals per cow per day: both cubicle number per AMS and feed bunk space per cubicle had a very small positive effect. Conversely, separation through a second AMS unit, the number of cubicles in the separation area, a straw area, the surface of the straw area and a split entry waiting area, individually had a negative effect on the number of refusals. Both the AMS types A3 and A4 induced a higher number of refusals compared to the A3N type AMS. Moreover, an AMS in the middle, when looking at the width position, had a higher number of refusals than one on the right position. In addition, one AMS per group and the walkway length also had a positive effect. If there were less than 15 cubicles between the AMS unit and the first crossover, there was a positive effect. However, both the length and the width position of the concentrates stall had a negative effect. Finally the barn model showed a positive effect if there were one or two cubicle rows per feed bunk length.

Table 3.5. Effect of barn layout variables on the number of refusals (simple regression procedure in which one independent variable is corrected for kg concentrates / cow and the random herd effect)

Variable	Class	n	Estimate	SE	DF	t Value	P
Cubicle number per AMS	Continuous[1]	1264	0.0037	0.0020	202.5	1.90	0.0584
Cubicle wall width	<=1,15 m	720	-0.0917	0.1440	148.1	-0.64	0.5253
	>1,15 m		0.0000	.	.	.	.
Cubicle wall length	<=2,65 m	696	-0.0791	0.0842	137.4	-0.94	0.3493
	>2,65 m		0.0000	.	.	.	.
Cubicle middle width	<=1,15 m	1234	0.0394	0.1120	247.8	0.35	0.7254
	>1,15 m		0.0000	.	.	.	.
Cubicle middle length	<=2,35 m	1186	0.0875	0.0663	248.0	1.32	0.1877
	>2,35 m		0.0000	.	.	.	.
Feed bunk space per cubicle	Continuous	1240	0.0004	0.0002	246.6	1.86	0.0644
Distance AMS to cubicles row	Continuous	1258	0.0000	0.0000	211.7	-0.87	0.3832
Separation possibility	Yes	1264	-0.0434	0.1205	252.7	-0.36	0.7194
	No		0.0000	.	.	.	.
Separation through 2nd AMS unit	Yes	1222	-0.3228	0.0648	271.9	-4.98	<.0001
	No		0.0000	.	.	.	.
Cubicle number separation area	<=4	1126	-0.1443	0.0697	218.6	-2.07	0.0397
	>4		0.0000	.	.	.	.
Straw area	Yes	1264	-0.1191	0.0474	231.8	-2.51	0.0127
	No		0.0000	.	.	.	.
Surface straw area	Continuous	1264	-0.0021	0.0006	229.8	-3.63	0.0004
Split entry waiting area	Yes	1264	-0.2359	0.0693	256.3	-3.40	0.0008
	No		0.0000	.	.	.	.
AMS Type	A3	1264	0.5647	0.2175	98.3	2.60	0.0109
	A4		0.2400	0.1025	110.3	2.34	0.0209
	A3N		0.0000	.	.	.	.
AMS left / right	Left	1264	0.0206	0.0317	169.2	0.65	0.5174
	Right		0.0000	.	.	.	.
AMS length position	Front	1264	0.0034	0.1985	154.7	0.02	0.9863
	Middle		-0.3030	0.2666	219.2	-1.14	0.2570
	End		0.0000	.	.	.	.
AMS width position	Left	1264	-0.0204	0.0312	149.2	-0.65	0.5135
	Middle		0.1361	0.0556	229.6	2.45	0.0150
	Right		0.0000	.	.	.	.
AMS alignment	Right-angled on Feed bunk	1264	-0.0047	0.1223	242.5	-0.04	0.9694
	Parallel to feed bunk front at feed bunk		0.0590	0.1414	182.2	0.42	0.6770
	Parallel to feed bunk front not at feed bunk		0.0000	.	.	.	.

Variable (continued)	Class	n	Estimate	SE	DF	t Value	P
AMS per group	1	1264	0.6552	0.2186	108.2	3.00	0.0034
	2		0.2095	0.2161	103.7	0.97	0.3344
	3		0.0000	.	.	.	.
Water trough distance to AMS	Continuous	921	0.0000	0.0000	157.6	-0.18	0.8580
Walk way length	Continuous	1252	0.0000	0.0000	195.2	-2.33	0.0210
Walk way width at feed bunk	<=3,5 m	1084	0.0839	0.0687	229.1	1.22	0.2232
	>3,5 m		0.0000	.	.	.	.
Walk way width in middle	<=2,5 m	1174	0.0338	0.0677	242.6	0.50	0.6180
	>2,5 m		0.0000	.	.	.	.
Walk way surface / cubicle	Continuous	1264	-0.0396	0.0273	241.8	-1.45	0.1476
Crossover position	<= 15 cubicles	1222	0.1841	0.0635	243.6	2.90	0.0041
	> 15 cubicles		0.0000	.	.	.	.
Walk way dead ends	0	1264	-0.0355	0.1087	254.6	-0.33	0.7440
	1		0.0846	0.1342	250.7	0.63	0.5289
	>1		0.0000	.	.	.	.
Concentrates stall length position	Begin cubicles row	1264	-0.2054	0.1873	211.5	-1.10	0.2738
	Middle cubicles row		-0.3591	0.0696	245.0	-5.16	<.0001
	End cubicles row		-0.2131	0.1833	239.0	-1.16	0.2463
	Not present		0.0000	.	.	.	.
Concentrates stall width position	At feed bunk walkway	1264	-0.4294	0.0691	260.6	-6.22	<.0001
	Middle row		0.0026	0.1045	243.7	0.02	0.9804
	Both		-0.4584	0.2136	106.6	-2.15	0.0341
	Not present		0.0000	.	.	.	.
Concentrates stall occupation	Continuous	471	-0.0010	0.0022	47.8	-0.44	0.6644
Barn model	<= 2 cubicle rows per feed bunk length	1018	0.1652	0.0877	205.7	1.88	0.0611
	>2 cubicle rows per feed bunk length		0.0000	.	.	.	.

[1] Mean cubicle number per AMS 60.5 ± 9.9, range 39 – 126; feed bunk space per cubicle 590.5 ± 134.8 mm, range 69.6 – 990.6; distance AMS to cubicles row 4904.3 ± 912.2 mm, range 2651 – 8077; surface straw area 31.8 ± 40.8 m^2, range 0 – 147.5; water trough distance to AMS 5083.9 ± 2638 mm, range 1812 – 20132; walk way length 42229.9 ± 11328 mm, range 23604 – 88642; walk way surface per cubicle 4.6 ± 1.0 m^2, range 0 – 7.5; concentrates stall occupation 86.8 ± 28.7 cubicles/stall, range 23.8 - 138

Multiple regression analysis

Table 3.6 shows the results of the multiple regression analysis on the number of refusals. The number of cubicles showed a small negative main effect, although it showed a positive effect for the interaction with kg concentrates / cow. The feed bunk space had a very small positive main effect on the number of refusals. However, less than four cubicles in a separation area and a split entry waiting area had a negative main effect. On the other hand, interaction of the cubicle number in the separation area with kg concentrates / cow showed a positive effect, so the negative main effect can be reduced by feeding more concentrates. An AMS of type A4 and one AMS unit per group both had a large positive main effect. The length and width position of the concentrates stall had a negative main effect when it was placed respectively at the beginning of a cubicles row and at the middle walkway. The interaction with kg concentrates / cow showed a negative effect for the length position and a positive effect for the width position. A barn model with one or two cubicle rows per feed bunk length induced a negative effect in the multiple regression analysis while it had a positive effect in the simple regression analysis. Finally, the interaction effect of walk way length was very small.

Table 3.6. Effect of barn layout variables on the number of refusals (multiple regression procedure in which all selected independent variables are corrected for kg concentrates / cow and the random herd effect n=874)

Effect	Class	Estimate	SE	DF	t Value	P
Intercept		1.3457	0.5351	258.20	2.5100	0.0125
Kg Concentrates Cow	Continuous	-0.3171	0.0889	448.10	-3.5700	0.0004
Cubicle number per AMS	Continuous	-0.0269	0.0065	360.70	-4.1700	<.0001
Feedbunk space per cubicle	Continuous	0.0014	0.0003	180.60	4.4400	<.0001
Cubicles separation area	<=4	-0.3660	0.1373	347.00	-2.6700	0.0080
	>4	0.0000	.	.	.	.
Split entry waiting area	Yes	-0.1985	0.0742	191.80	-2.6800	0.0081
	No	0.0000	.	.	.	.
AMS Type	A3	0.2492	0.3945	63.51	0.6300	0.5299
	A4	0.3880	0.1321	68.56	2.9400	0.0045
	A3N	0.0000	.	.	.	.
AMS per group	1	1.0597	0.2514	81.33	4.2200	<.0001
	2	0.3503	0.2360	67.80	1.4800	0.1423
	3	0.0000	.	.	.	.
Walk way length	Continuous	0.0000	0.0000	265.60	0.3200	0.7456
Concentrates stall Length position	Begin cubicles row	-1.8492	0.7397	283.20	-2.5000	0.0130
	Middle cubicles row	-0.3327	0.3791	121.90	-0.8800	0.3819
	End cubicles row	-0.9661	0.5659	321.20	-1.7100	0.0888
	Not present	0.0000	.	.	.	.
Concentrates stall Width position	At feedbunk walkway	0.8015	0.4337	158.00	1.8500	0.0665
	Middle walkway	1.1018	0.4299	144.20	2.5600	0.0114
	Both	0.0000	.	.	.	.
	Not present	0.0000	.	.	.	.
Barn Model	<= 2 cubicle rows per feedbunk length	-0.3972	0.1249	203.10	-3.1800	0.0017
	>2 cubicle rows per feedbunk length	0.0000	.	.	.	.
Kg Concentrates Cow*Cubicle number per AMS	Continuous	0.0030	0.0011	417.10	2.7200	0.0069
Kg Concentrates Cow*Cubicles separation area	<=4	0.0908	0.0300	386.80	3.0300	0.0026
	>4	0.0000	.	.	.	.
Kg Concentrates Cow*Walk way length	Continuous	0.0000	0.0000	749.40	1.0400	0.2985
Kg Concentrates Cow*Concentrates stall Length position	Begin cubicles row	0.4660	0.1785	787.80	2.6100	0.0092
	Middle cubicles row	0.0562	0.0856	786.20	0.6600	0.5111
	End cubicles row	0.2312	0.1338	818.50	1.7300	0.0844
	Not present	0.0000	.	.	.	.

Effect (continued)	Class	Estimate	SE	DF	t Value	P
Kg Concentrates Cow*Concentrates stall Width position	At feedbunk walkway	-0.2692	0.0955	844.00	-2.8200	0.0049
	Middle walkway	-0.2728	0.0958	780.20	-2.8500	0.0045
	Both	0.0000	.	.	.	.
	Not present	0.0000	.	.	.	.
Random effects						
Farm		0.212	0.040			
Month		0.544	0.037			
Random error		0.101	0.008			

3.4. Milking frequency

On average, the milking frequency was 2.7 times per cow per day (range: 1.3 - 3.7, standard deviation 0.4 times a day). A maximum of 397 observations were used in the simple regression analysis.

Simple regression analysis

The results of the analysis are shown in Table 3.7 and indicate that the following variables had a significant (p<0.10) effect on milking frequency: The width of the cubicles beside the wall smaller than 1.15m had a negative effect. On the other hand, a separation possibility and a split entry waiting area both had a positive effect while a separation area with less than five cubicles induced a negative effect. The A3 type AMS showed a significantly positive effect on milking frequency compared to the A3N type. Furthermore, the length position of the AMS had a positive effect if it was placed in the front of the barn. Finally the length position of the concentrates stall had a negative effect if it was placed at the end of a cubicle row.

Table 3.7. Effect of barn layout variables on milking frequency (simple regression procedure in which one independent variable is corrected for kg concentrates / cow)

Variable	Class	n	Estimate	SE	DF	t Value	P
Cubicle number per AMS	Continuous[1]	397	0.0009	0.0010	65.0	0.86	0.3919
Cubicle wall width	<=1,15 m	325	-0.1373	0.0570	54.0	-2.41	0.0194
	>1,15 m		0.0000	.	.	.	.
Cubicle wall length	<=2,65 m	313	-0.0219	0.0304	51.9	-0.72	0.4749
	>2,65 m		0.0000	.	.	.	.
Cubicle middle width	<=1,15 m	379	-0.0589	0.0595	62.2	-0.99	0.3260
	>1,15 m		0.0000	.	.	.	.
Cubicle middle length	<=2,35 m	367	-0.0097	0.0314	60.6	-0.31	0.7577
	>2,35 m		0.0000	.	.	.	.
Feed bunk space per cubicle	Continuous	397	-0.0001	0.0001	66.2	-0.48	0.6331
Distance AMS to cubicles row	Continuous	397	0.0000	0.0000	65.3	0.92	0.3620
Separation possibility	Yes	397	0.1361	0.0533	65.1	2.55	0.0131
	No		0.0000	.	.	.	.

Variable (continued)	Class	n	Estimate	SE	DF	t Value	P
Cubicle number separation area	<=4	341	-0.0809	0.0452	55.6	-1.79	0.0785
	>4		0.0000	.	.	.	.
Straw area	Yes	397	0.0366	0.0293	65.6	1.25	0.2165
	No		0.0000	.	.	.	.
Surface straw area	Continuous	397	0.0004	0.0004	65.7	1.01	0.3161
Split entry waiting area	Yes	397	0.0883	0.0290	65.5	3.04	0.0034
	No		0.0000	.	.	.	.
AMS Type	A3	397	0.1146	0.0554	66.5	2.07	0.0426
	A4		0.0064	0.0323	64.6	0.20	0.8445
	A3N		0.0000	.	.	.	.
AMS left / right	Left	397	-0.0317	0.0295	65.5	-1.08	0.2856
	Right		0.0000	.	.	.	.
AMS length position	Front	397	0.1259	0.0746	64.7	1.69	0.0960
	Middle		0.0000	.	.	.	.
AMS width position	Left	397	-0.0975	0.1104	63.9	-0.88	0.3803
	Middle		-0.0227	0.0840	63.7	-0.27	0.7882
	Right		0.0000	.	.	.	.
AMS alignment	Right-angled on Feed bunk	397	0.0540	0.0526	64.0	1.03	0.3084
	Parallel to feed bunk front at feed bunk		0.0454	0.0968	64.7	0.47	0.6403
	Parallel to feed bunk front not at feed bunk		0.0000	.	.	.	.
Water trough distance to AMS	Continuous	300	0.0000	0.0000	48.0	-1.18	0.2457
Walk way length	Continuous	397	0.0000	0.0000	64.9	-0.25	0.8029
Walk way width at feed bunk	<=3,5 m	361	-0.0159	0.0319	59.7	-0.50	0.6208
	>3,5 m		0.0000	.	.	.	.
Walk way width in middle	<=2,5 m	379	-0.0146	0.0302	62.5	-0.48	0.6314
	>2,5 m		0.0000	.	.	.	.
Walk way surface / cubicle	Continuous	397	-0.0068	0.0160	65.4	-0.43	0.6717
Crossover position	<= 15 cubicles	385	0.0120	0.0303	63.6	0.40	0.6933
	> 15 cubicles		0.0000	.	.	.	.
Walk way dead ends	0	397	-0.0254	0.0510	64.8	-0.50	0.6204
	1		-0.0325	0.0646	64.3	-0.50	0.6168
	>1		0.0000	.	.	.	.
Concentrates stall length position	Begin cubicles row	397	-0.0233	0.0897	62.7	-0.26	0.7957
	Middle cubicles row		0.0040	0.0391	63.7	0.10	0.9187
	End cubicles row		-0.1925	0.0953	64.1	-2.02	0.0477
	Not present		0.0000	.	.	.	.
Concentrates stall width position	At feed bunk walkway	397	0.0067	0.0415	63.7	0.16	0.8722
	Middle row		-0.0858	0.0586	65.0	-1.46	0.1480
	Not present		0.0000	.	.	.	.
Concentrates stall occupation	Continuous	89	-0.0014	0.0033	12.8	-0.41	0.6877
Barn model	<= 2 cubicle rows per feed bunk length	379	-0.0181	0.0310	62.6	-0.58	0.5617
	>2 cubicle rows per feed bunk length		0.0000	.	.	.	.

[1] Mean cubicle number per AMS 63.8 ± 13.8, range 44 – 126; feed bunk space per cubicle 599.7 ± 145.4 mm, range 69.6 – 990.6; distance AMS to cubicles row 4471.5 ± 845.6 mm, range 2651 – 7283; surface straw area 22.4 ± 33.1 m^2, range 0 – 147.5; water trough distance to AMS 4536.6 ± 1553 mm, range 1812 – 11039; walk way length 35733.2 ± 7857 mm, range 23604 – 61800; walk way surface per cubicle 4.4 ± 0.9 m^2, range 3.0 – 7.5; concentrates stall occupation 62.5 ± 9.3 cubicles/stall, range 50 - 79

Multiple regression analysis

The results of the multiple regression analysis on milking frequency are shown in Table 3.8. If there was a separation possibility, the milking frequency strongly increased. The same goes for a concentrates stall which had the length position in the middle of a cubicle row. However, the interaction effect of the same position gave a negative effect, which means that when more concentrates are fed, the effect of this position is reduced. The interaction between kg concentrates / cow and split entry waiting area showed a small positive effect. But when the main effect of a split entry waiting area was included, both the main and interaction effect had a negative influence.

Table 3.8. Effect of barn layout variables on milking frequency (multiple regression procedure in which all selected independent variables are corrected for kg concentrates / cow n=287)

Effect	Class	Estimate	SE	DF	t Value	P
Intercept		0.3431	0.0701	48.2	4.89	<.0001
Kg Concentrates / Cow	Continuous	0.0627	0.0066	273.0	9.48	<.0001
Split entry waiting area	Yes	0.0079	0.0548	225.4	0.14	0.8856
	No	0.0000	.	.	.	.
Separation possibility	Yes	0.3872	0.0709	44.9	5.46	<.0001
	No	0.0000	.	.	.	.
Concentrates stall length position	Begin cubicles row	0.0002	0.1394	227.4	0.00	0.9988
	Middle cubicles row	0.1956	0.0671	248.7	2.91	0.0039
	End cubicles row	-0.2290	0.1495	159.5	-1.53	0.1276
	Not present	0.0000	.	.	.	.
Kg Concentrates / Cow * Split entry waiting area	Yes	0.0087	0.0095	273.2	0.92	0.3580
	No	0.0000	.	.	.	.
Kg Concentrates / Cow * Concentrates stall length position	Begin cubicles row	-0.0099	0.0315	275.8	-0.31	0.7544
	Middle cubicles row	-0.0409	0.0116	265.7	-3.54	0.0005
	End cubicles row	-0.0387	0.0264	230.4	-1.47	0.1434
	Not present	0.0000	.	.	.	.
Random effects						
Month		0.9235	0.0155			
Random error		0.0186	0.0035			

3.5. Free milk time

On average, the free milk time was 23.5 per cent per day per AMS (range: 5.1-70.5, standard deviation: 10.1 per cent of a day), indicating that an AMS unit is not milking but is waiting for a cow to be milked for 23.5% of the day. A maximum of 1262 observations was used in the simple regression analysis.

Simple regression analysis

From all variables tested, only the following variables showed a significant (p<0.1) effect on free milk time (Table 3.9): as the number of cubicles per AMS increased, the free milk time slightly increased. The possibility of separation didn't have an effect while separation trough a second AMS unit had a negative effect. Furthermore, a straw area, the surface of this straw area and a split entry waiting area individually give a significantly lower free milk time compared to situations without one of those. When looking at the position of the AMS unit in the barn, the width position did have a positive effect when the AMS was positioned in the middle compared to one that was positioned on the right side. Moreover, if there was only one AMS in a group of cows, the free milk time was higher compared to 3 AMS units per group. Walkway length had a very small negative effect on the free milk time. In addition, a concentrates stall with length position in the middle of a cubicles row and one with a width position at the feed bunk, individually had a negative effect on the free milk time compared to a situation in which no concentrates stall was present. A higher occupation of a concentrates stall had a small negative effect on the free milk time. In contrast, a barn model with one or two cubicle rows per feed bunk length induced a higher free milk time than a barn with more than two cubicle rows per feed bunk length.

Table 3.9. Effect of barn layout variables on the free milk time (simple regression procedure in which one independent variable is corrected for kg concentrates / cow and the random herd effect)

Variable	Class	n	Estimate	SE	DF	t Value	P
Cubicle number per AMS	Continuous	1262	0.1531	0.0448	242	3.42	0.0007
Cubicle wall width	<=1,15 m	718	-5.4437	3.5384	123	-1.54	0.1265
	>1,15 m		0.0000	.	.	.	.
Cubicle wall length	<=2,65 m	695	-1.9399	1.8408	131	-1.05	0.2939
	>2,65 m		0.0000	.	.	.	.
Cubicle middle width	<=1,15 m	1232	-1.6227	2.7574	259	-0.59	0.5567
	>1,15 m		0.0000	.	.	.	.
Cubicle middle length	<=2,35 m	1185	1.9865	1.4133	265	1.41	0.1610
	>2,35 m		0.0000	.	.	.	.
Feed bunk space per cubicle	Continuous	1238	0.0019	0.0046	275	0.42	0.6770
Distance AMS to cubicles row	Continuous	1256	0.0003	0.0009	218	0.35	0.7290
Separation possibility	Yes	1262	-1.3538	2.5476	282	-0.53	0.5956
	No		0.0000	.	.	.	.
Separation through 2nd AMS unit	Yes	1220	-5.7909	1.3697	288	-4.23	<.0001
	No		0.0000	.	.	.	.
Cubicle number separation area	<=4	1124	-1.7889	1.3775	255	-1.3	0.1952
	>4		0.0000	.	.	.	.
Straw area	Yes	1262	-4.4068	0.9113	255	-4.84	<.0001
	No		0.0000	.	.	.	.
Surface straw area	Continuous	1262	-0.0660	0.0113	260	-5.82	<.0001
Split entry waiting area	Yes	1262	-3.7610	1.4574	277	-2.58	0.0104
	No		0.0000	.	.	.	.

Variable (continued)	Class	n	Estimate	SE	DF	t Value	P
AMS Type	A3	1262	5.2595	4.9599	101	1.06	0.2915
	A4		-3.5099	2.2901	104	-1.53	0.1284
	A3N		0.0000	.	.	.	.
AMS left / right	Left	1262	0.4169	0.6473	197	0.64	0.5203
	Right		0.0000	.	.	.	.
AMS length position	Front	1262	1.2470	4.3620	181	0.29	0.7753
	Middle		1.6229	5.6869	247	0.29	0.7756
	End		0.0000	.	.	.	.
AMS width position	Left	1262	-0.2167	0.6168	173	-0.35	0.7258
	Middle		3.7820	1.1229	253	3.37	0.0009
	Right		0.0000	.	.	.	.
AMS alignment	Right-angled on Feed bunk	1262	-3.4902	2.6087	272	-1.34	0.1820
	Parallel to feed bunk front at feed bunk		-2.8807	3.3164	226	-0.87	0.3860
	Parallel to feed bunk front not at feed bunk		0.0000	.	.	.	.
AMS per group	1	1262	13.1087	4.4565	110	2.94	0.0040
	2		5.0367	4.3763	103	1.15	0.2524
	3		0.0000	.	.	.	.
Water trough distance to AMS	Continuous	919	0.0000	0.0003	189	0.1	0.9168
Walk way length	Continuous	1250	-0.0002	0.0001	205	-2.29	0.0230
Walk way width at feed bunk	<=3,5 m	1082	0.0069	1.4552	249	0	0.9962
	>3,5 m		0.0000	.	.	.	.
Walk way width in middle	<=2,5 m	1172	0.8927	1.4630	256	0.61	0.5423
	>2,5 m		0.0000	.	.	.	.
Walk way surface / cubicle	Continuous	1262	-0.4843	0.5815	273	-0.83	0.4057
Crossover position	<= 15 cubicles	1220	1.8125	1.4144	252	1.28	0.2012
	> 15 cubicles		0.0000	.	.	.	.
Walk way dead ends	0	1262	-3.2717	2.5005	272	-1.31	0.1918
	1		-2.8981	3.1207	270	-0.93	0.3539
	>1		0.0000	.	.	.	.
Concentrates stall length position	Begin cubicles row	1262	-0.8833	3.4102	271	-0.26	0.7958
	Middle cubicles row		-10.1460	1.5256	249	-6.65	<.0001
	End cubicles row		-3.5683	3.8393	279	-0.93	0.3535
	Not present		0.0000	.	.	.	.
Concentrates stall width position	At feed bunk walkway	1262	-10.1376	1.4807	287	-6.85	<.0001
	Middle walkway		-1.6802	2.2482	257	-0.75	0.4555
	Both		-9.4216	4.6259	100	-2.04	0.0443
	Not present		0.0000	.	.	.	.
Concentrates stall occupation	Continuous	471	-0.0735	0.0400	50.7	-1.84	0.0720
Barn model	<= 2 cubicle rows per feed bunk length	1016	3.5318	1.9222	208	1.84	0.0676
	>2 cubicle rows per feed bunk length		0.0000	.	.	.	.

[1] Mean cubicle number per AMS 60.5 ± 9.9, range 39 – 126; feed bunk space per cubicle 590.6 ± 134.8 mm, range 69.6 – 990.6; distance AMS to cubicles row 4904.2 ± 912.8 mm, range 2651 – 8077; surface straw area 31.8 ± 40.9 m^2, range 0 – 147.5; water trough distance to AMS 5083.0 ± 2641 mm, range 1812 – 20132; walk way length 42246.4 ± 11330 mm, range 23604 – 88642; walk way surface per cubicle 4.6 ± 1.0 m^2, range 0 – 7.5; concentrates stall occupation 86.8 ± 28.7 cubicles/stall, range 23.8 - 138

Multiple regression analysis

The results of the multiple regression analysis are shown in Table 3.10. These results show that the number of cubicles per AMS unit had a small positive main effect on free milk time. Moreover, a straw area had a significantly negative main effect on free milk time. For the split entry waiting area, the positive main effect differs from the simple regression analysis since it had a significantly negative effect on the free milk time in the simple regression analysis. This may be the case because interaction of concentrates fed with the split entry waiting area gave a negative effect on free milk time. When looking at the length position of the concentrates stall, if it was positioned at the beginning of the cubicles row, it had a strong positive main effect on the free milk time compared to a situation where no concentrates stall was present. In contrast, the interaction between concentrates fed and the length position of the concentrates stall gave a negative effect when it was positioned at the beginning of a cubicles row. The width position of the concentrates stall also had an effect on the free milk time of the AMS. That is, if the concentrates stall was positioned at the feed bunk, the free milk time was lower compared to a situation where there was no concentrates stall present. However, the interaction with concentrates fed for a concentrates stall at the feed bunk was significantly positive. In a barn model with one or two cubicle rows per feed bunk length, the free milk time was significantly higher than in a barn with more than three rows per feed bunk length.

Table 3.10. Effect of barn layout variables on free milk time (multiple regression procedure in which all selected independent variables are corrected for kg concentrates / cow and the random herd effect n=986)

Effect	Class	Estimate	SE	DF	t Value	P
Intercept		34.5233	3.1231	263.0	11.05	<.0001
Kg Concentrates / Cow	Continuous	-5.1819	0.5014	521.0	-10.33	<.0001
Cubicle number per AMS	Continuous	0.1660	0.0404	210.3	4.11	<.0001
Straw area	Yes	-3.3131	0.8911	221.0	-3.72	0.0003
	No	0.0000	.	.	.	.
Split entry waiting area	Yes	8.0540	2.4374	316.7	3.30	0.0011
	No	0.0000	.	.	.	.
Concentrates stall Length position	Begin cubicles row	37.6435	13.6604	474.7	2.76	0.0061
	Middle cubicles row	0.0071	8.3663	185.7	0.00	0.9993
	End cubicles row	3.1994	13.8423	522.2	0.23	0.8173
	Not present	0.0000	.	.	.	.
Concentrates stall Width position	At feedbunk walkway	-23.2116	9.1617	224.5	-2.53	0.0120
	Middle walkway	-0.4652	9.6262	216.1	-0.05	0.9615
	Both	0.0000	.	.	.	.
	Not present	0.0000	.	.	.	.

Variable (continued)	Class	n	Estimate	SE	DF	t Value	P
Barn Model	<= 2 cubicle rows per feedbunk length		6.7501	1.8593	249.4	3.63	0.0003
	>2 cubicle rows per feedbunk length		0.0000	.	.	.	.
Kg Concentrates / Cow*Split entry waiting area	Yes		-2.5334	0.6647	503.1	-3.81	0.0002
	No		0.0000	.	.	.	.
Kg Concentrates / Cow*Length position	Begin cubicles row		-11.4296	3.7439	927.1	-3.05	0.0023
	Middle cubicles row		-3.4479	2.0397	883.5	-1.69	0.0913
	End cubicles row		-3.4449	3.4042	961.4	-1.01	0.3118
	Not present		0.0000	.	.	.	.
Kg Concentrates / Cow*CS Width position	At feedbunk walkway		6.7488	2.1816	936.7	3.09	0.0020
	Middle walkway		2.2343	2.3163	909.5	0.96	0.3350
	Both		0.0000	.	.	.	.
	Not present		0.0000	.	.	.	.
Random effects							
Farm			124.2300	20.3602			
Month			0.4598	0.0351			
Random error			19.0937	1.2461			

4. Discussion

This research tried to find out which barn layout indicators affect AMS efficiency by having an influence on performance indicators ('milk yield per AMS', 'milk yield per minute', 'number of refusals', 'milking frequency' and 'free milk time'). This is done by means of a simple regression analysis. Furthermore, a multiple regression analysis was performed to try to get a prediction of the performance indicators (Dohoo et al., 2009). This was done by a backward elimination procedure because it is based on significance levels and not on model fit statistics. Model fit statistics are not comparable for models that do not have the same number of observations, as was the case in this research. The interaction with the amount of concentrates fed was taken into account because concentrates are used to attract cows to the AMS and thus may influence performance indicators (Halachmi et al., 2003; Koning C. de, 2010).

The results of the simple regression analysis can be related to performance indicators and so with AMS efficiency. Milk yield per AMS unit is an important measure in this case, which indicates AMS efficiency. The higher the milk yield per AMS unit, the lower the capital costs per litre of milk that is produced (Sonck & Donkers, 1995; Koning & Rodenburg, 2004). Furthermore, performance indicators have an influence if they are at an optimal level. Maximization of milk yield per minute (Castro et al., 2012), improving milking frequency and reducing free milk time (Dooren et al., 2004) are important to achieve optimal performance. The number of refusals may be an important measure for the willingness of the cows to visit the AMS system. A relatively high number of refusals indicates that the cows are visiting the AMS quite often, this may indicate that the farmer has to bring less cows to the AMS, which saves time.

This research is the first to mention a split entry waiting area as barn layout variable. In this research, the presence of a split entry waiting area had a significant positive effect on the milking frequency of the cows. This can be caused by improved access to a AMS unit, since the cows locked up in the separation area do not block this access. Moreover, the presence of a split entry waiting area had a significantly negative effect on free milk time. This may be because low dominance cows in the waiting area will choose to be milked when no other cows are trying to access the AMS (Ketelaar-de Lauwere et al., 1996). Furthermore, the split entry waiting area may increase the milk yield per minute, since low dominance cows are less disturbed in accessing the AMS (Ketelaar-de Lauwere et al., 1996). Less disturbance can cause a reduction in stress, which will increase milk yield per minute (Szentléleki et al., 2015). The positive influence of a split entry waiting area on milking frequency, free milk time and milk yield per minute may, thus, have a positive effect on milk yield per AMS and increase AMS efficiency.

In addition, ‘separation through a second AMS unit’ is also not mentioned in previous research. It caused a significant decrease in free milk time. This may be the case because capacity of the second AMS unit is used for separating cows from the group (for example because of health problems). Therefore, this part of total capacity cannot be used for milking cows, and thus means a lower free milk time.

The presence of a straw area for separation and the surface of the straw area (in m^2) had a positive effect on milk yield per AMS, milk yield per minute and reduced the free milk time. These results were in line with Naess et al. (2011) stating that the milk yield per cow will increase if a separation pen of at least 10 m^2 is available.

Feed bunk space did not significantly affect milk yield per AMS unit. This result is in line with previous research, that describes that the consumption rate of the cows increases when the feed bunk space is reduced (Olofsson, 1999). However, for sufficient feed consumption, a minimum of 0.2 meter of feed bunk space per cow is required (Friend et al., 1977).

In this research, an AMS which was aligned right angled on the feed bunk induced a higher milk yield per minute. This may be related to the fact that the cow is able to look at herd mates while she is in the AMS unit. Being able to see other cows, therefore, may reduce stress levels. Reduced stress levels have been associated with increased milk yield per minute (Szentléleki et al., 2015).

Both length and width position of the concentrates stall had a significant positive effect on milk yield per AMS. Moreover, length and width position of the concentrates stall significantly reduced free milk time compared to a situation in which no concentrates stall is present. The presence of a concentrates stall makes it possible to feed more concentrates. Those concentrates lead to a higher milk yield per cow (Lawrence et al., 2015) and thus they can lead to a higher milk yield per AMS. The free milk time of the AMS may be reduced because cows with a higher milk yield need more time to be completely milked in the AMS unit.

From these results can be seen that barn layout indicators in the area around the AMS (‘separation possibility’, ‘straw area’, ‘the surface of the straw area’ and ‘split entry waiting area’) often have a significantly positive effect on performance, indicating that the area around the AMS is very important in the design of a new barn.

The variables with a significant outcome in the univariate analyses and that are not mentioned in the aforementioned paragraphs had an effect on AMS unit performance indicators, and thus on technical efficiency. This involved the following variables: ‘Cubicle number per AMS’, ‘Cubicle wall width‘, ‘Separation possibility’, ‘Cubicles separation area’, ‘AMS type’, ‘AMS length position’, ‘AMS width position’, ‘AMS per group’, ‘Walk way length’, ‘Crossover position’, ‘Walk way dead ends’, ‘Concentrates stall occupation’ and ‘Barn model’. However, the effects could not be explained by the current or previous research. Future research, therefore, is required to clarify the results of these barn layout effects on technical efficiency of AMS units.

As can be seen from the results of the simple regression analyses, the number of refusals was significantly affected by some barn layout variables. There is very few research conducted in which the number of refusals was included as a performance measure. However, the number of refusals may be an indicator for the willingness of the cows to visit the AMS unit. In addition, barn layout variables which had a positive effect on the other performance indicators, did not have a positive effect on number of refusals. These were for example: ‘straw area’, ‘surface of the straw area’, ‘split entry waiting area’, ‘concentrates stall length position’ and ‘concentrates stall width position’. Future research may give an explanation for these contradicting results.

In this research the multiple regression analyses was performed to get an insight in the predictability of the dependent variables. Unfortunately, it appeared that barn layout variables did not explain much of the variation in the dependent variables. On the other hand, random herd effect and the month effect did explain a large part of the variation in the dependent variables. This may be because feed and management factors may have a bigger effect on performance indicators compared to the barn layout variables. For example, feeding concentrates has an effect on the visitation behaviour of the cows (Halachmi et al., 2003). Moreover, a good management ability of a farmer and if conditions where the farm is in are good, have a positive influence on herd productivity (Bewley et al., 2001). In addition Jacobs & Siegford (2012) described that management plays a big role in the performance of an AMS because previous studies described contradicting results regarding same aspects of AMS.

The results of this research have to be interpreted with care because it is not sure that the actual barn is built like the layout indicated. Moreover, it is not clear if the barn is actually used like the layout suggested. In future research, barns can be visited in practice to control for differences between the layout on paper and the real situation (for example: are the water trough placed on the indicated position? Is de barn indeed divided into two separate groups?). In addition, the number of unique cows milked per AMS unit was known. However, if there was more than one AMS unit per group of cows, cows can visit both units. Therefore, the precise number of cows in a group with more than one AMS unit is not known. This number could have provided more insight in the occupation of barn elements like: feed bunk space, walk way surface and concentrates stalls. The occupation of these elements may have an influence on performance, for example the occupation of the feed bunk space affects milk yield per cow (DeVries & Keyserlingk, 2006). Furthermore, the number of cows in a group can have an influence on the performance indicators. For example more cows in a group may have a positive influence on the milk yield per AMS unit and this may reduce the free milk time of the AMS unit. In future research on the relationship between barn layout and AMS efficiency, the number of cows in a group should be taken into account. Lastly, it is possible that one of two AMS units per group showed extreme values on one of the performance indicators. These outliers may have not affected the results too much, because the layout of this barn is included two times and therefore individually related to each AMS. Thus, the two AMS units may level out each other.

5. Conclusion

The objective of this research was to find freestall barn layout indicators which have an influence on performance indicators and thereby on AMS efficiency. In conclusion, barn layout indicators affect performance indicators (‘milk yield per AMS’, ‘milk yield per minute’, ‘number of refusals’, ‘milking frequency’ and ‘free milk time’). Particularly indicators associated with the AMS area seem to affect performance indicators, and thus seem important for the development of new barn layouts. These effects are relatively small because management and feed influences have a bigger effect on performance. Therefore, the multiple regression analysis in this research did not give a good predictability of performance indicators. Future (experimental) research may give a better prediction for the influence of individual barn layout indicators on AMS efficiency.

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Appendix

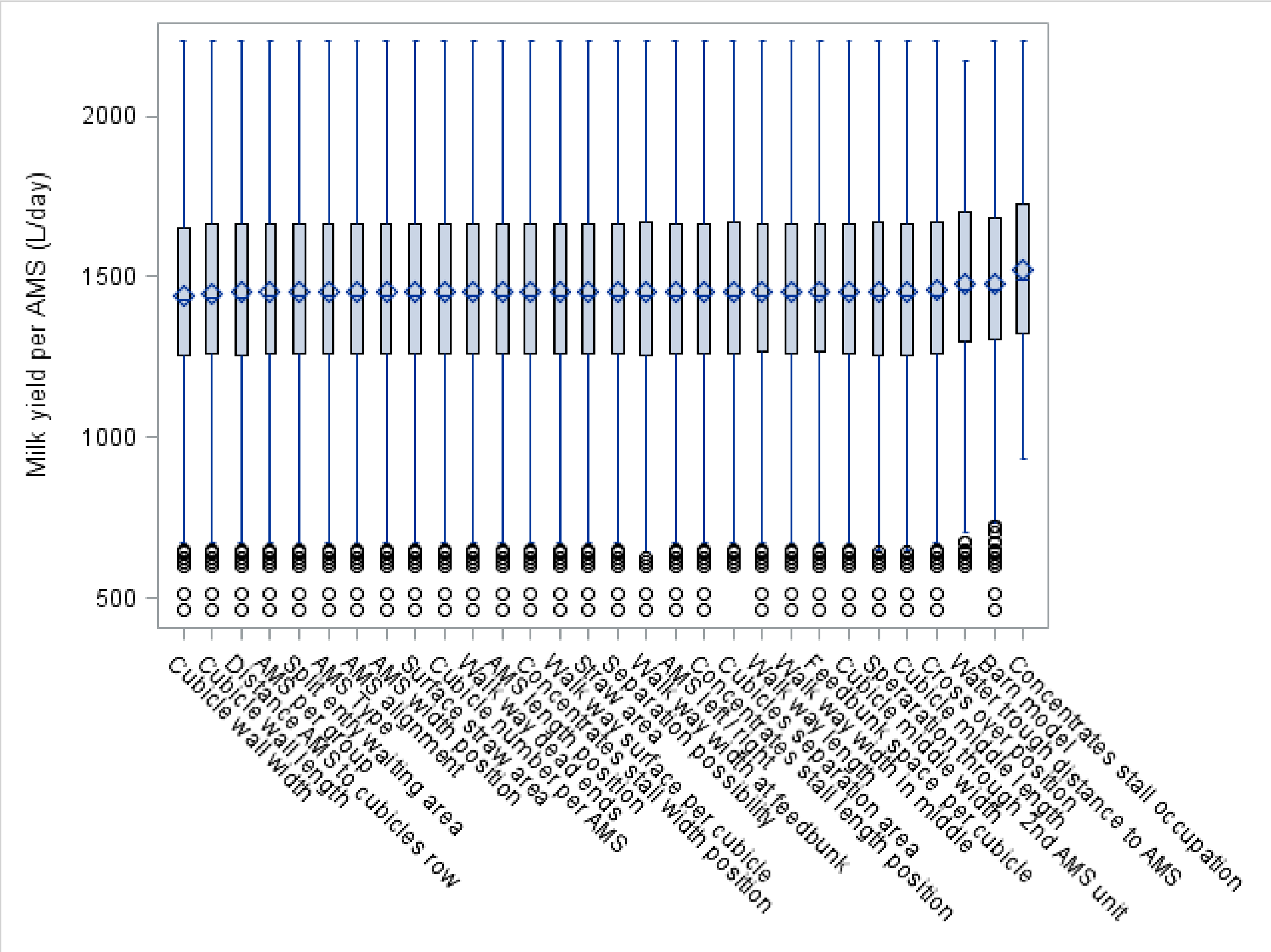

Figure A 1. Boxplot milk yield per AMS for each barn layout variable (ordered by median)

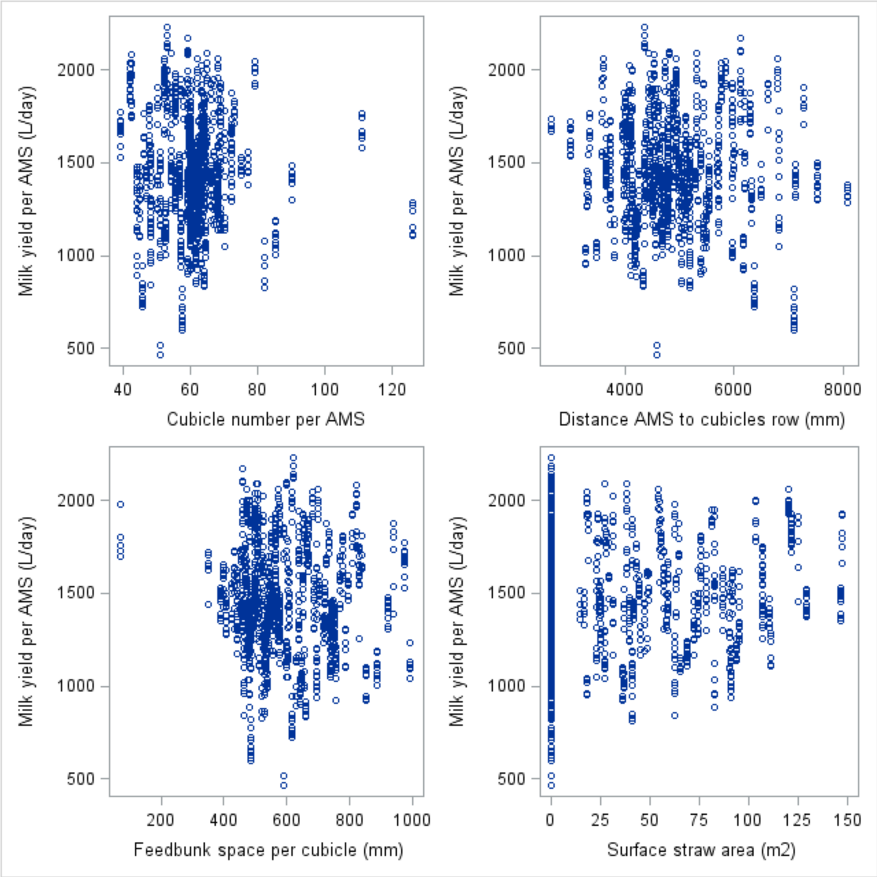

Figure A 2. Scatterplot of observations on continuous barn layout indicators with respect to milk yield per AMS

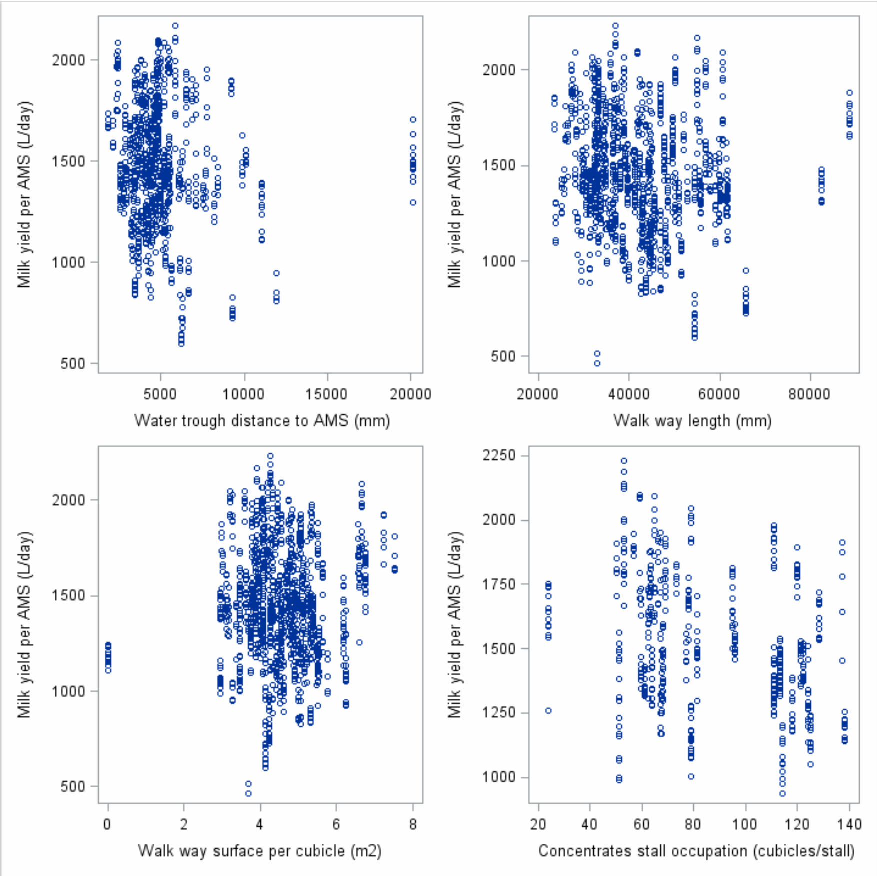

Figure A 3. Scatterplot of observations on continuous barn layout indicators with respect to milk yield per AMS

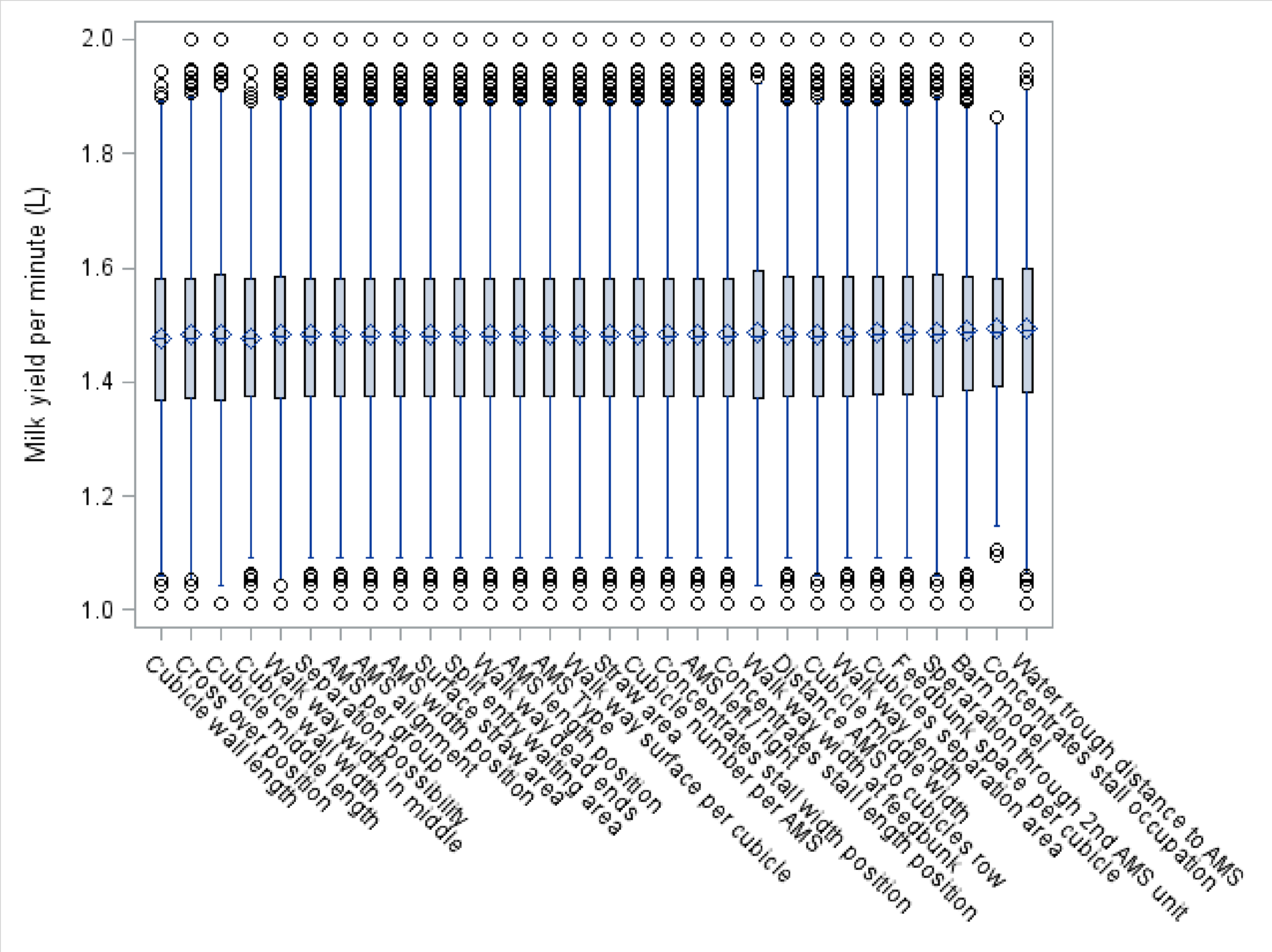

Figure A 4. Boxplot milk yield per minute for each barn layout variable (ordered by median)

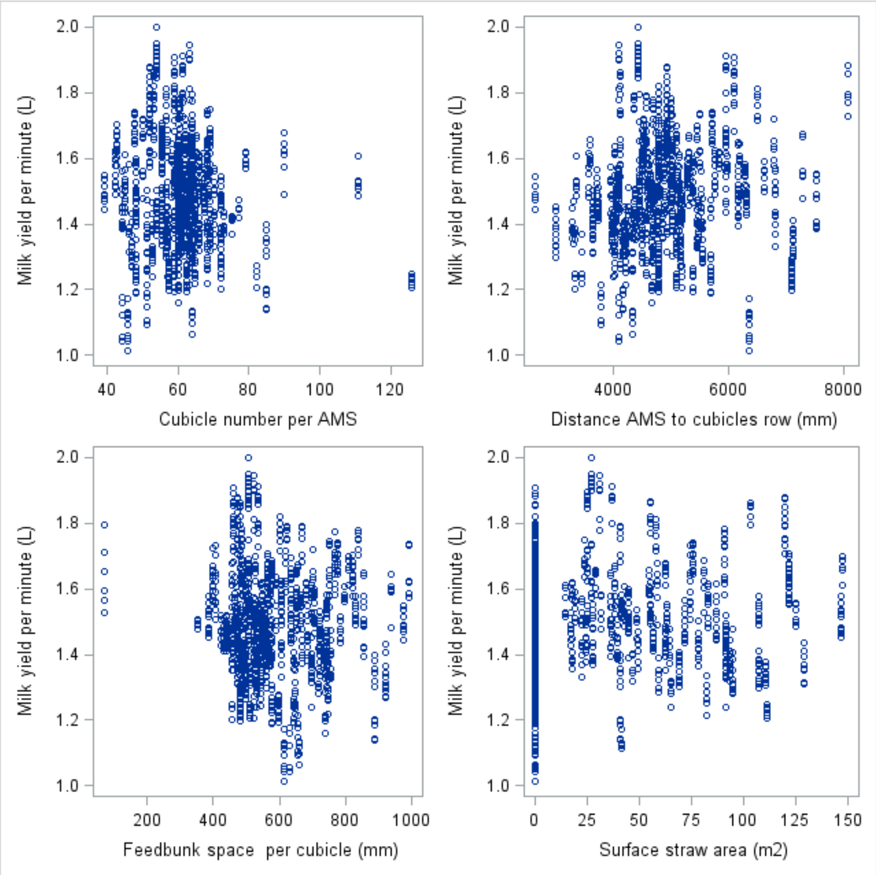

Figure A 5. Scatterplot of observations on continuous barn layout indicators with respect to milk yield per minute

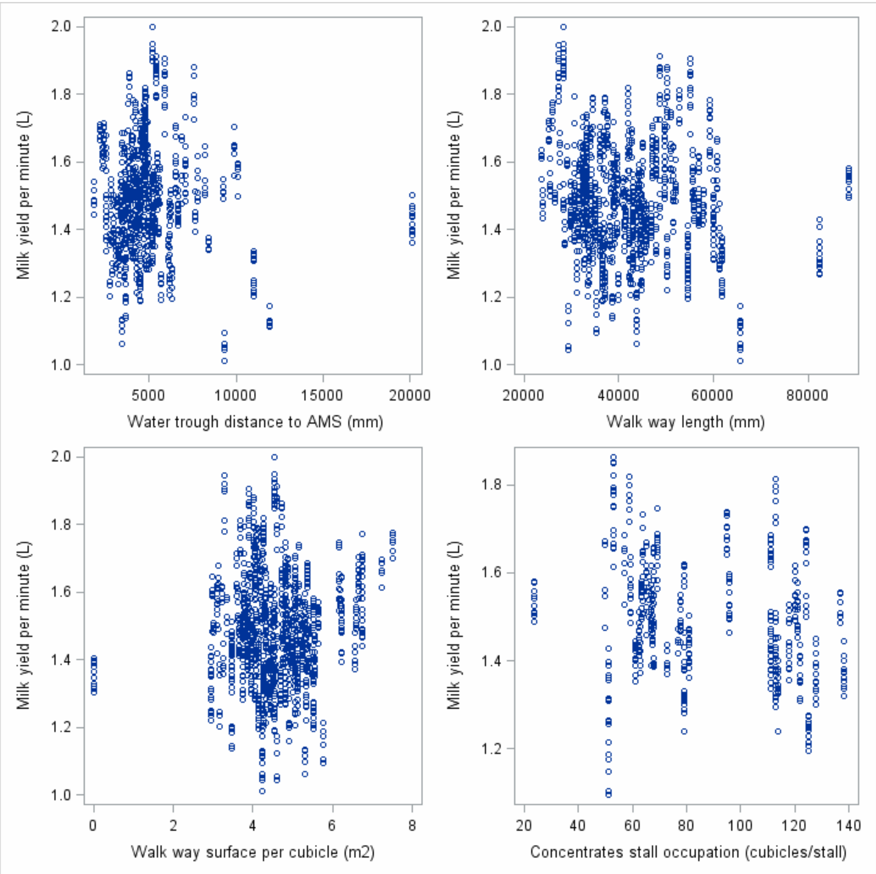

Figure A 6. Scatterplot of observations on continuous barn layout indicators with respect to milk yield per minute

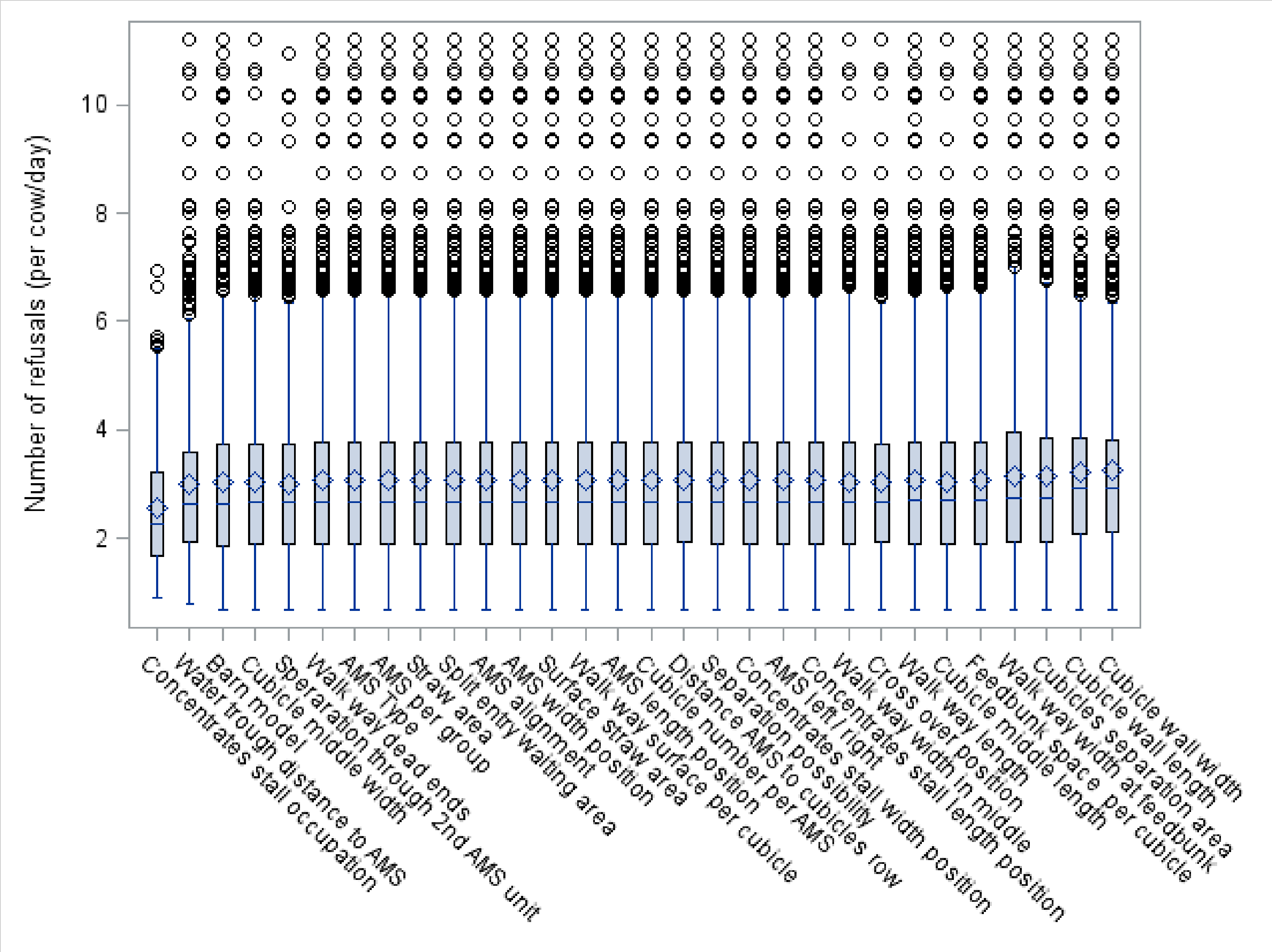

Figure A 7. Boxplot number of refusals for each barn layout variable (ordered by median)

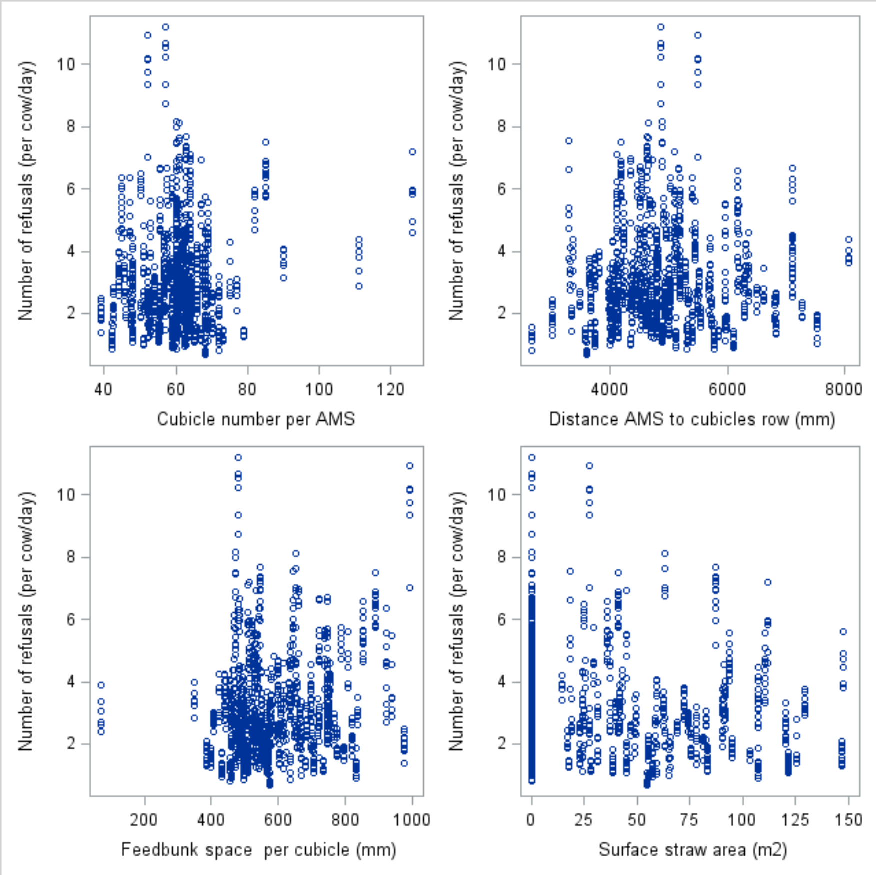

Figure A 8. Scatterplot of observations on continuous barn layout indicators with respect to number of refusals

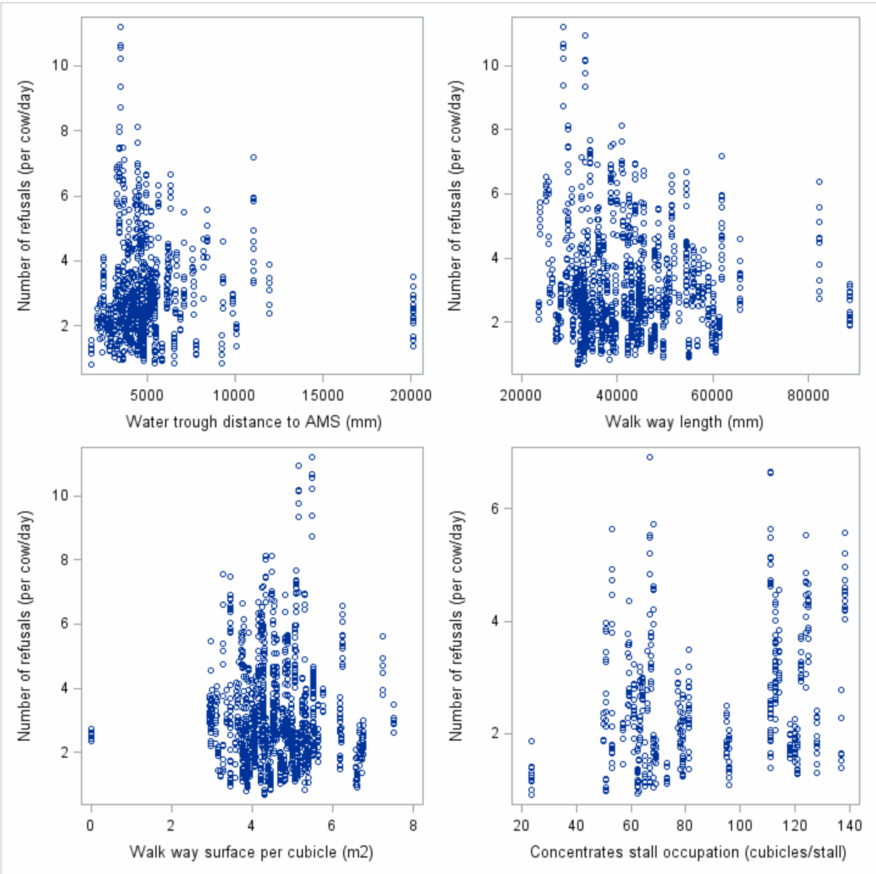

Figure A 9. Scatterplot of observations on continuous barn layout indicators with respect to number of refusals

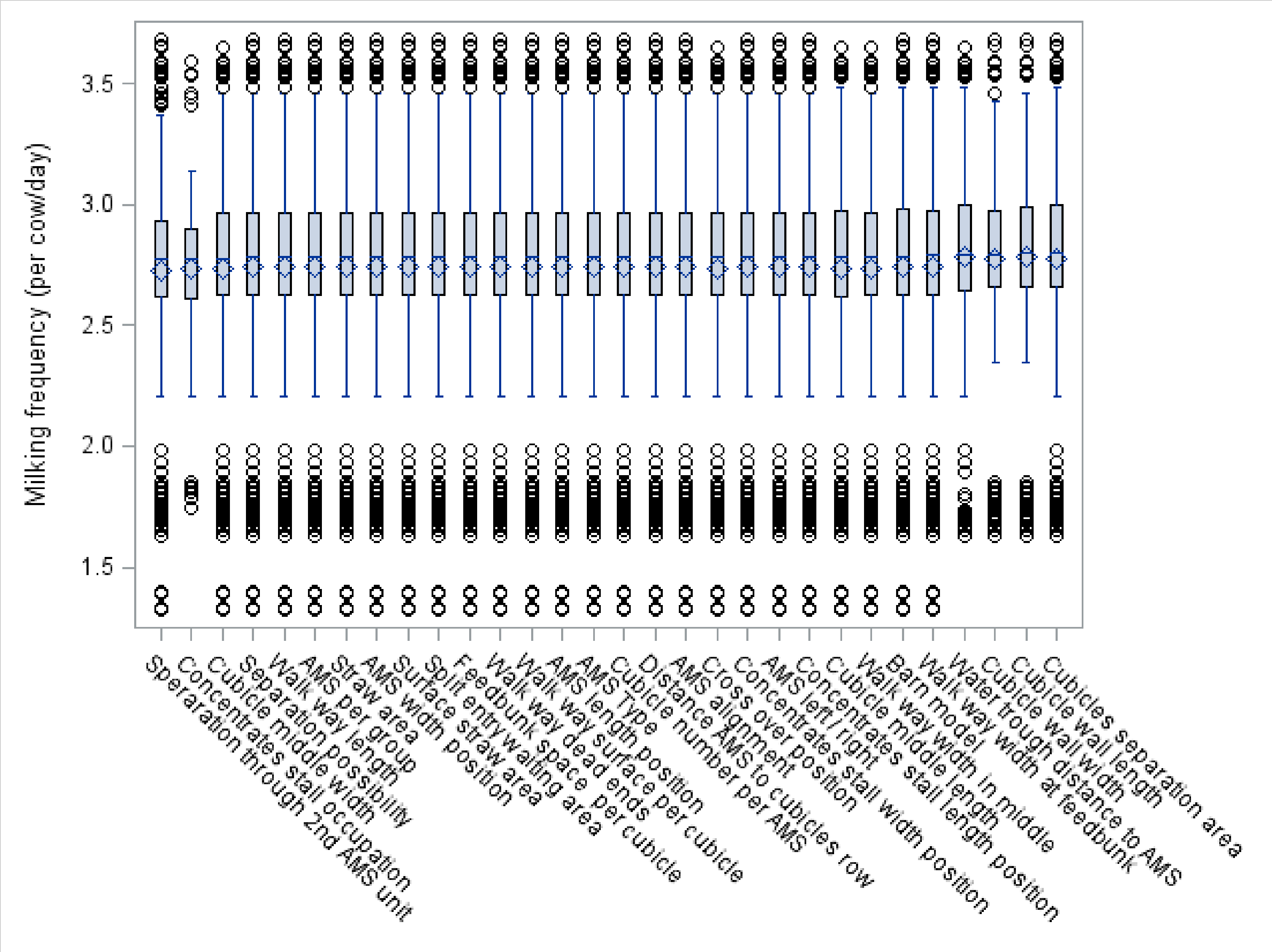

Figure A 10. Boxplot milking frequency for each barn layout variable (ordered by median)

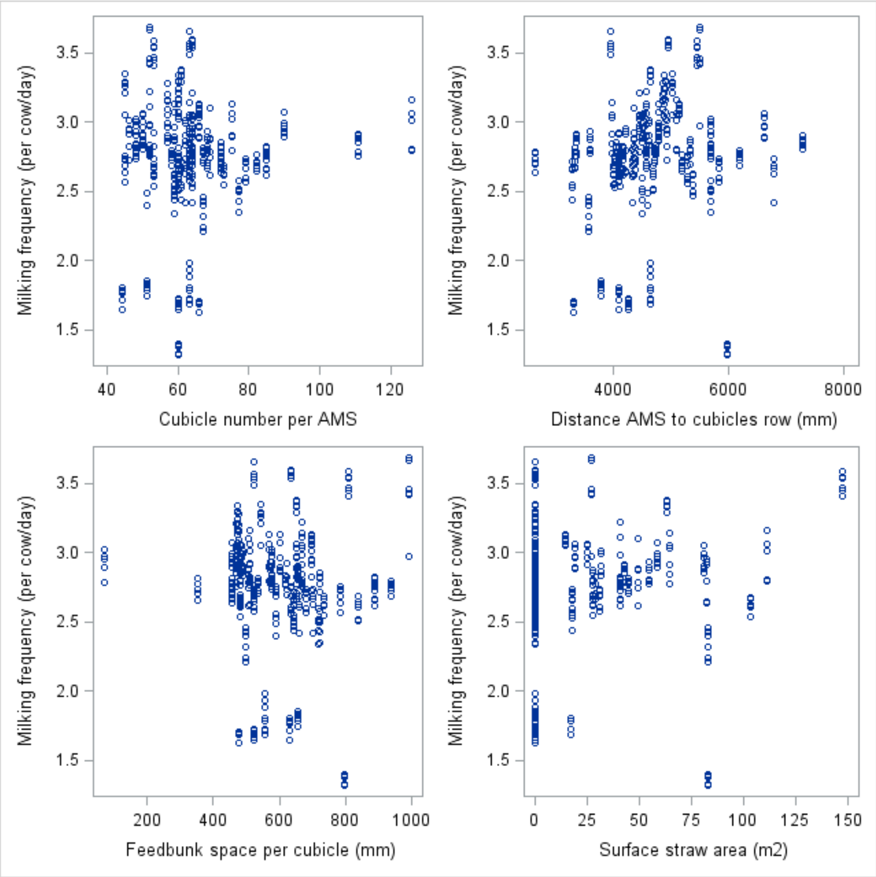

Figure A 11. Scatterplot of observations on continuous barn layout indicators with respect to milking frequency

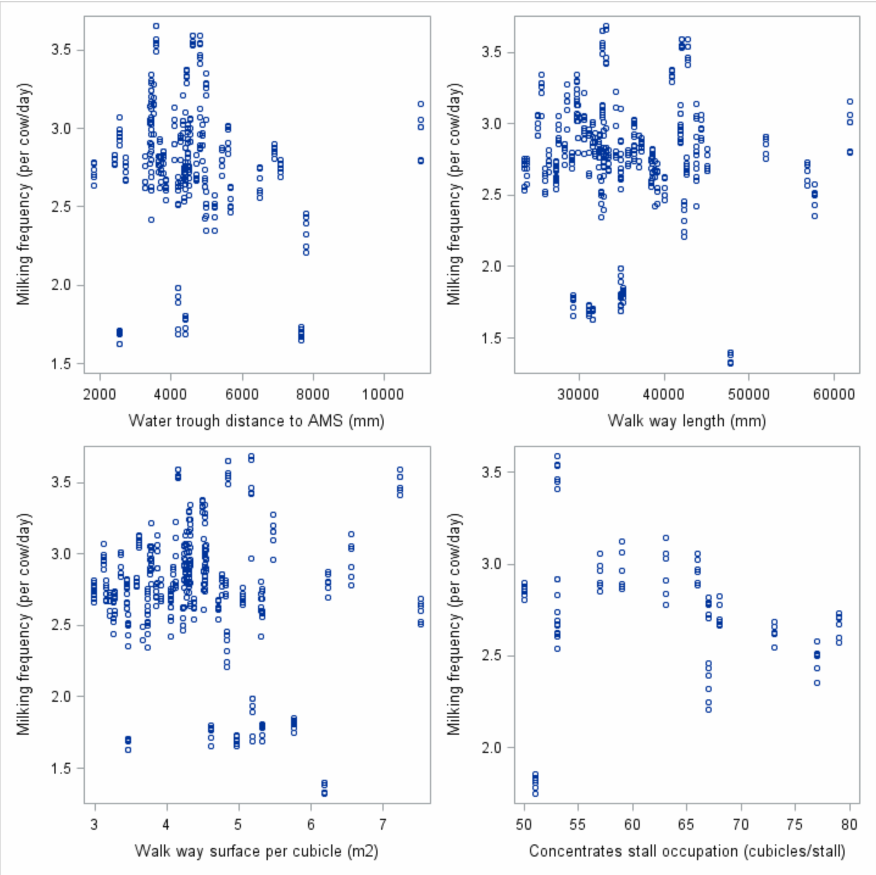

Figure A 12. Scatterplot of observations on continuous barn layout indicators with respect to milking frequency

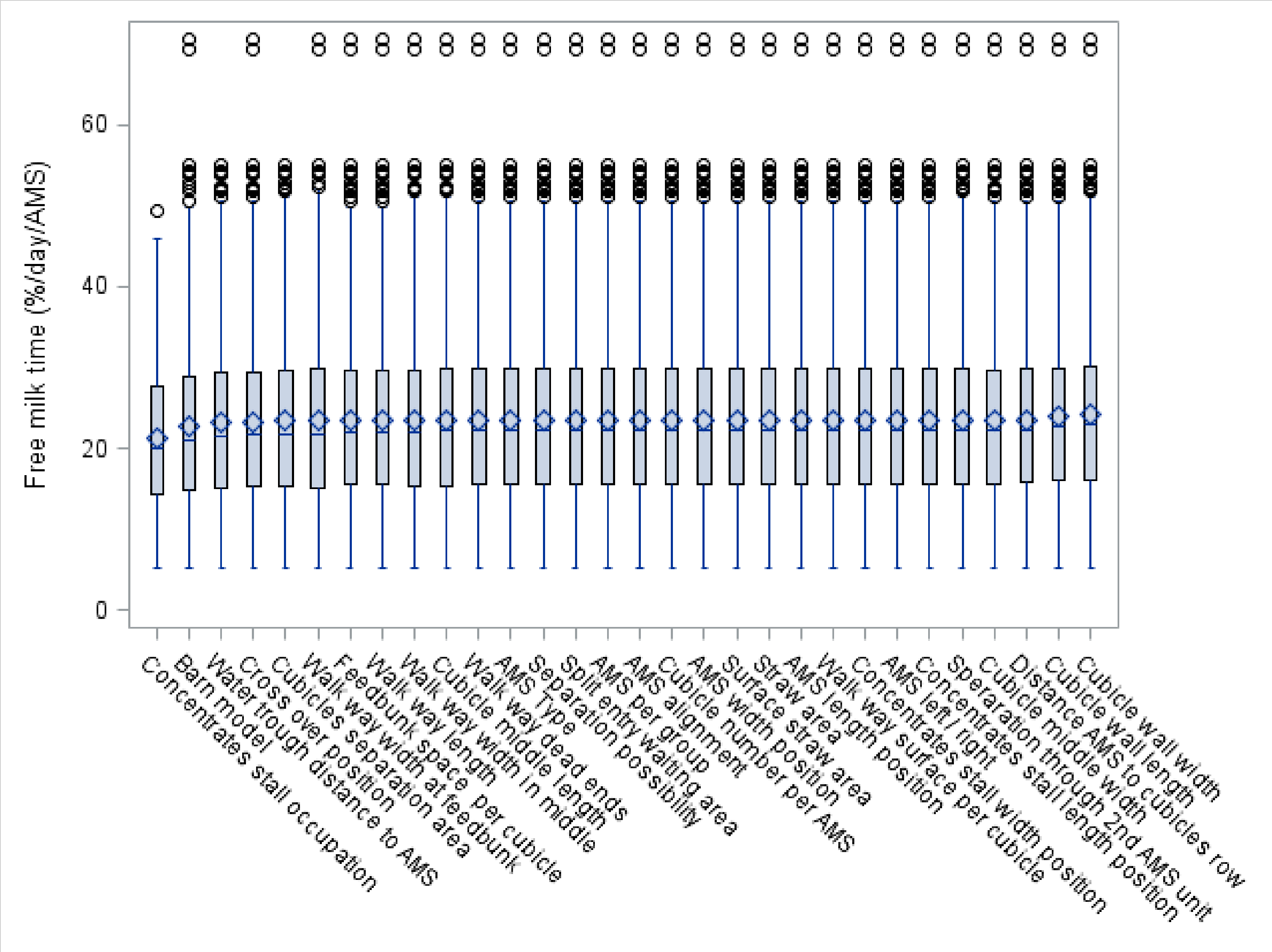

Figure A 13. Boxplot free milk time for each barn layout variable (ordered by median)

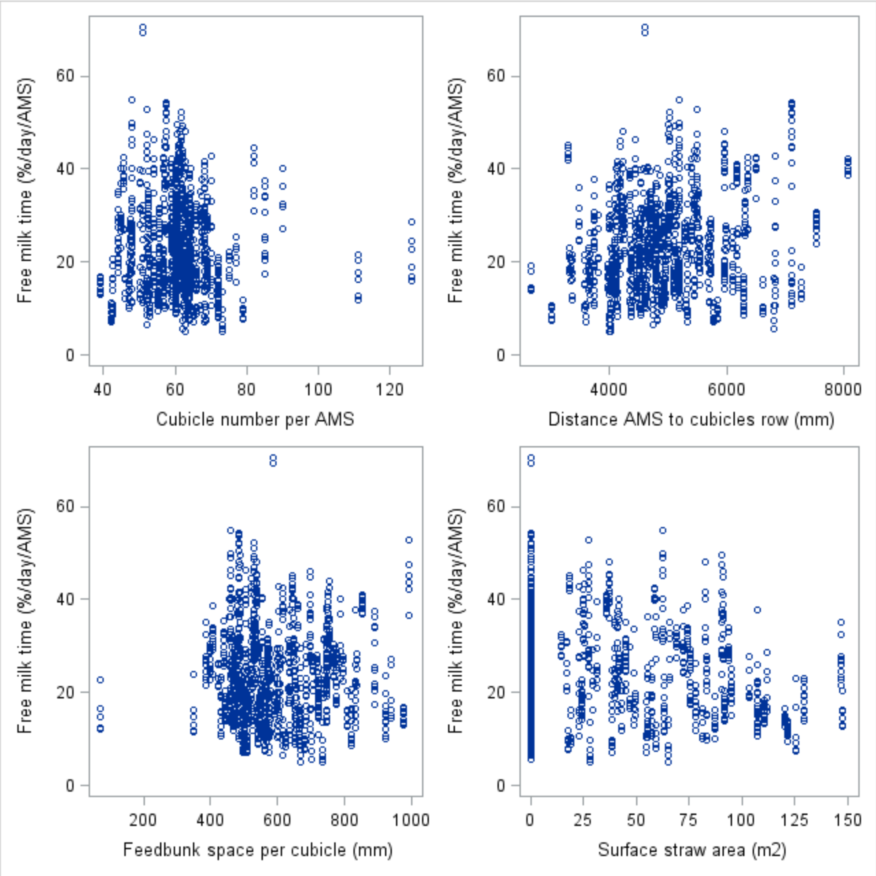

Figure A 14. Scatterplot of observations on continuous barn layout indicators with respect to free milk time

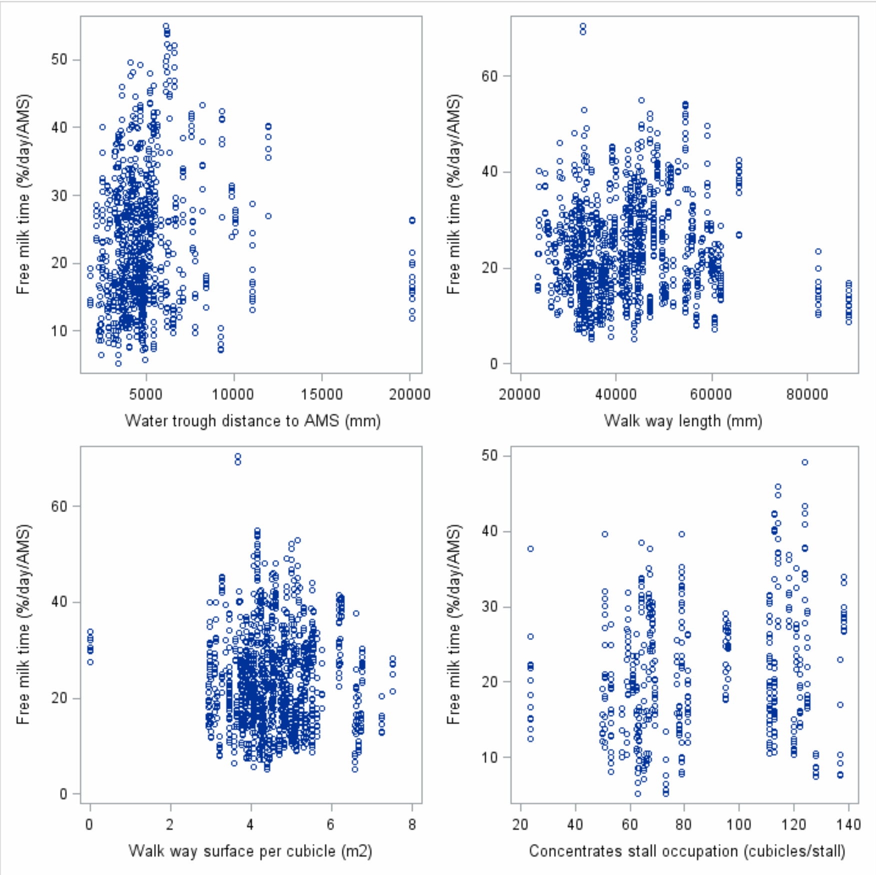

Figure A 15. Scatterplot of observations on continuous barn layout indicators with respect to free milk time