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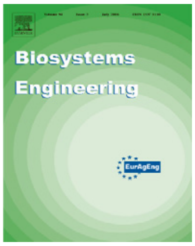

Research Paper: AP—Animal Production Technology

Behaviour-based simulation of facility demand of laying hens

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The objective is to show that it is possible to estimate facility demand of laying hens with discrete-event modelling. This is a step in the development of a tool to estimate the required facility capacity in different housing environments. We explored the possibility to model results from behavioural observations with a discrete-event simulation model. Video recordings were made of eight hens housed in a pen with ample facilities. For the first dataset we observed hens individually during 2 days using continuous focal sampling. From these data we calculated input parameters: probability density functions of durations of behaviours and a transition matrix. Verification, with data from the same dataset, showed that it was possible to simulate facility demand. For a second dataset we observed the hens simultaneously during 5 days using instantaneous scan sampling, yielding data on facility utilisation only. Validation with these data showed that, in general, the model results were comparable. Including group behaviour in future models, however, could improve the prediction. In conclusion, discrete-event modelling is a potential tool to estimate facility demand of laying hens.

1. Introduction

Animal welfare is a major motive for developing new housing systems for farm animals. Concern for animal welfare has led to legislation regarding minimum housing requirements for several species. For laying hens, this resulted in an EU ban on battery cages in 2012, and in development of enriched cages and 'alternative' systems (Mollenhorst and de Boer, 2004; EC, 1999). 'Alternative' systems include single-level and multi-level systems. The latter are generally called aviaries. Both occur with or without outdoor runs (Animal Sciences Group, 2006).

In order to assure good animal welfare, animals must be able to fulfil their physiological and ethological needs (Weeks and Nicol, 2006). These needs imply that normal behaviour can be expressed (Wechsler, 2007), which subsequently requires certain commodities, i.e. facilities. Many studies have paid attention to only one or few behaviours in order to obtain more knowledge about specific facility demands (e.g. Albentosa and Cooper, 2004; Cooper and Appleby, 2003; Olsson and Keeling, 2002). For developing housing systems, however, it is necessary to make an integral assessment of the facility demand of laying hens, because the availability of certain facilities can influence several performed behaviours and therewith the fulfilment of needs. Facilities are defined here in terms of commodity-related spatial requirements of the hens for performing distinct

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Nomenclature

t	length of an interval (s)
Y_t	frequency of all intervals with length $>t$
N_w	total number of intervals within bouts
N_b	total number of intervals between bouts
λ_w	rate parameter of the distribution function of within bout intervals (s^{-1})
λ_b	rate parameters of the distribution functions of between bout intervals (s^{-1})
T_c	bout criterion (s)

behaviours. One way to assess the facility demand of laying hens is to observe their behaviour in an environment with ample facilities. The utilisation of facilities in this situation can be regarded as the facility demand of the laying hen. Afterwards, behavioural observations can be used to assess whether hens are also able to fulfil their needs in more restricted housing environments. Performing behavioural observations in many possible environments, however, is very time consuming. Therefore, we need tools to assess facility demands without so many behavioural observations. A model that is able to predict the facility demand in different situations could be a solution. When we wish to compare many different housing environments, we expect that it will take less effort to develop and validate a model, compared to performing behavioural observations for all environments. In future, this may result in a model that is able to predict facility utilisation in a variety of housing environments, which could be a useful tool in behaviour-based design of housing systems of laying hens.

In quantitative ethology, continuous time records of animal behaviour are often studied as Markov chains (Haccou and Meelis, 1992; Metz et al., 1983). A basic assumption of a continuous time Markov chain is that the probability of a transition between states is independent of both the previous sequence of states (i.e. is a first-order discrete Markov chain) and the time the current state has already endured (Haccou and Meelis, 1992; Metz et al., 1983). This implies that we can describe the behaviour of the hens in a house by means of sojourn times in states and transitions between those states. Systems with these properties can be modelled with discrete-event simulation models (Law and Kelton, 2000). In these models, events are the transitions from one state to another. These models are commonly applied to study queuing problems (Kettenis, 1997). Halachmi (2000) showed that they are useful for the simulation of cow behaviour, especially with respect to queuing before the automatic milking system, as the basis for the design of optimal robotic milking barns. This, however, was a situation with (more or less) forced cow traffic, which means that cows were not able to switch from one to whichever other facility they wanted. In houses for laying hens, these restrictions are not present, which makes the model more complicated. For simple systems, performance measures, like average number of hens at a facility, can be computed mathematically (e.g. queuing theory). For realistic models of complex systems, however, simulation is usually required (Banks et al., 2001).

The three main stages in computer simulation are modelling, programming and experimentation (Pidd, 1992). During the modelling stage the structure of the model (conceptual model) is developed, whereas during the programming stage the model is implemented in a computer program and input parameters are defined. During both phases verification (i.e. determining whether the conceptual model has been correctly translated into the computer "program") and validation (i.e. determining whether the simulation model is an accurate representation of the system for the objectives of the study) are essential (Law and Kelton, 2000). In this study, validation was performed by comparing the results of the simulation model with a validation dataset and by performing a sensitivity analysis. During the experimentation stage, a valid model can be used to predict, among others, effects of changes.

The objective of this paper is to show that it is possible to estimate facility demand of laying hens with discrete-event modelling. Therefore, we explored the possibility to model results from behavioural observations of individual hens with a discrete-event simulation model. This was verified by comparing the model results with data from the same dataset and validated with data from a dataset on facility utilisation of the whole flock. This paper is a step in the development of a tool to estimate the required facility capacity in different environments.

2. Materials and methods

2.1. Animals

Eight Bovans Goldline commercial hens arrived at the farm at 17 weeks of age. All hens wore a kind of 'backpack' that consisted of a piece of cloth of about 10 × 20 cm with two cords around the wings. Each 'backpack' was marked with a unique symbol (circle, triangle, etc.) for individual recognition. The 'backpacks' were made in such a way that minimal interference with normal behaviour was expected. Furthermore, hens were accustomed to it when observations started.

2.2. Housing and management

To observe their behaviour, eight hens were housed in a separate pen at the experimental farm of Schothorst Feed Research BV (Lelystad, the Netherlands). This pen was visually separated from other pens in the same compartment and measured 2.97 × 4.60 m. The main part was covered with a layer of approximately 10 cm of sand, while an area of 1.20 × 1.95 m was made up of an elevated grid (Fig. 1). The pen contained eight nest boxes (49 × 30 cm each, arranged in two levels, with a perch in front of the second level of nest boxes), three perches (2 m each, at different heights: 30, 60 and 90 cm above the sand), two round feeders and one round drinker. Feed and water were continuously available. This resulted in a

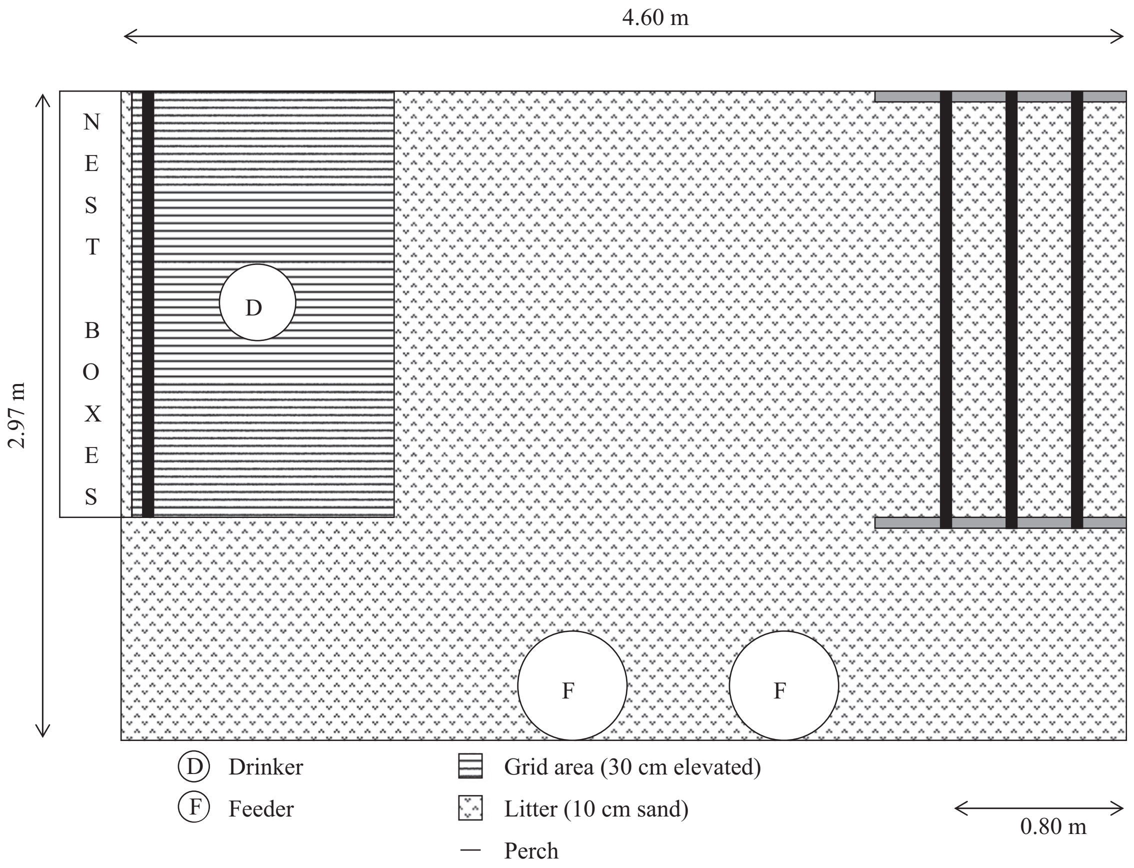

Fig. 1 – Ground plan of the pen.

situation with ample facilities, but which was still comparable to commercial (indoor) systems.

Normal management practice was performed, with only one control visit (less than 100 s) in the morning. During this visit the caretaker inspected the flock and the pen, scattered a hand of grain in the litter and raked it. The main light (12 lx at floor level) was turned on at 1:00 am and turned off at 5:00 pm. A tube light above the perches created a period of dim light of 3 min before the main light was turned on and 15 min after the main light was turned off.

2.3. *Data collection*

Video recordings were made with one analogue camera during the 16-h light period. This camera was positioned in the middle of the pen at the ceiling and connected with a capture device to a PC. In principle, every second day was recorded. Sometimes, however, the interval was larger due to weekends or computer problems.

Two datasets were collected: one with behavioural observations of individual hens for model definition and one with observations of facility utilisation of the whole flock for model validation. Both datasets were collected in the same house with the same animals in two consecutive periods.

For the behavioural observations, we recorded 16 days in order to obtain two recorded days per hen. The hens were between 23 and 28 weeks old and the laying rate was about 97% (number of eggs/number of hens present on a certain day). We used continuous focal sampling, which meant that the behaviour of one hen was observed during the whole light period of 16 h (Martin and Bateson, 1993, pp. 84–85, 88–90). This method is very laborious, but was necessary, because we needed distribution functions of durations of behaviours and a transition matrix, containing the probabilities of transitions between the different states. The eight hens were randomly assigned numbers 1 through 8. On the first and the ninth day, hen 1 was observed, on the second and tenth day, hen 2, etc. We used the ethogram as shown in Table 1. Behaviour and location were recorded simultaneously as two different categories. Within each category elements were mutually exclusive. Behaviour was coded with the computer program Observer® (Noldus Information Technology, Wageningen, the Netherlands) and one person made the observations for all 16 days.

For the observations of facility utilisation, we recorded 5 days when the hens were between 29 and 30 weeks old. This time we used instantaneous scan sampling, which meant that every 5 min the behaviour of all hens was recorded (Martin and Bateson, 1993, pp. 85–87, 90–91). We could use this method, because for validation we needed only information about the facility utilisation. We also simplified the ethogram, because short elements of behaviour are hard to observe reliably by scan sampling and they were not necessary for the validation of the model. Aggressive, beak and feather pecking were merged to ‘pecking’. Escape, flying and walking were merged to ‘moving’. And feather ruffling, stretching and wing flapping were merged to ‘wing or leg

Table 1 – Ethogram used for continuous focal sampling

Abbr.[a]	Behaviour	Description
AP	Aggressive pecking	Pecking at head, back or neck
BP	Beak pecking	Pecking at beak of another bird (mostly directed to feed particles)
DB	Dust bathing	Laying down in substrate, making fluttering movements and shaking dust out of the feathers
DR	Drinking	Drinking water from the drinkers
ES	Escape	Running away in case of attack or threat
FE	Feeding	Eating feed from the feeding trough
FL	Flying	Fly more than 0.5 m without touching the ground or other facility
FP	Feather pecking	Pecking at feathers of another hen
FR	Feather ruffling	The neck is stretched, the ruff is raised, the other feathers are ruffled and the whole body is shaken
NS	Not seen	Not seen (out of sight)
OT	Others	Behaviour not mentioned in this ethogram
PR	Preening	Standing or sitting turning the head and start manipulating feathers of the body using the beak
SC	Ground scratching	Scraping with foot over floor/litter (this also includes pecking grains from the litter)
SI	Sitting	Sitting idle (body on floor or perch)
SP	Sparring	Two hens kicking each other with their feet and spurs
SR	Stretching	Stretching wing and/or leg
ST	Standing	Standing idle (no contact body to floor)
WA	Walking	Walking more than 2 steps
WF	Wing flapping	Making flapping movements (more than one) with the wings
Abbr.	**Location**	**Description**
A	Nest perch	On the nest perch (in front of the upper nest boxes)
D	Drinking area	Head within about 5 cm from drinkers
F	Feeding area	Head within about 5 cm from feeding trough
G	Grid area	On the elevated grid (except drinking area)
L	Litter area	On the floor area covered with litter (except feeding area)
N	Nests	Inside a nest box
P	Perches	On the elevated perches

[a] Abbr. = abbreviation.

movements'. One person, who was trained by the person who collected the first dataset, made the observations for all 5 days.

2.4. *Data handling*

2.4.1. *Behavioural observations*

The dataset was checked for errors during different phases of data handling in order to prevent the model definition from being based on erroneous data. We checked whether impossible combinations appeared (e.g. drinking in the feeding area) and whether there were outliers in frequency distributions of durations. All suspected cases were checked with the video files and data were corrected according to the observations.

A behavioural occurrence is defined here as the observed period in which a hen is performing a specific behaviour. Behavioural occurrences related to the animals' needs commonly occur in clusters. This is most recognised in research on feeding behaviour, where clusters are called 'meals'. Elements of feeding occur with short intervals within meals and with longer intervals between meals (Metz, 1975). The clusters are generally called bouts and can be applied to other behaviours as well. A bout criterion must be calculated in order to distinguish between the short, within bout, and long, between bout, intervals. Bout criteria were calculated, under the assumption that both distributions are negative-exponential, with the following formulas:

$$Y_t = N_w \exp(-\lambda_w t) + N_b \exp(-\lambda_b t) \tag{1}$$

with Y_t = frequency of all intervals with length $>t$, N_w and N_b = total number of intervals within and between bouts and λ_w and λ_b = rate parameters of the distribution functions of within and between bout intervals, and

$$T_c = (1/(\lambda_w - \lambda_b)) \log((N_w\lambda_w)/(N_b\lambda_b)) \tag{2}$$

with T_c = bout criterion (Slater and Lester, 1982; Tolkamp et al., 1998). This bout criterion minimises the total number of incorrectly classified intervals (Slater and Lester, 1982).

When the interval between two occurrences of the same behaviour was shorter than the bout criterion, then all intermediate behavioural elements were neglected, irrespective of which behaviour. The whole period was then considered as one bout. This resulted in absorbing many behavioural occurrences of the same, but also of other behaviours, within the bouts. For feeding bouts, for example, this meant that 89% of the non-feeding time that was absorbed within the bouts consisted of standing or walking and 10% was scratching, which is a feeding-related behaviour.

Bout criteria were calculated for all behaviours for which the distribution function of interval lengths pointed to the presence of two negative exponential distributions (visual inspection of log survivorship curves (Sibly et al., 1990)). In this study these were feeding, drinking, dust bathing, scratching in the litter and preening on the perch. When calculating bouts, we checked whether bouts coincided, e.g. whether drinking occurrences were included in a feeding bout. Only scratching and preening were absorbed by other bouts. Before calculating a bout criterion for these two behaviours, therefore, intervals and interval distributions had to be recalculated after the feeding, drinking and dust bathing bouts were defined, because otherwise bouts would overlap.

After bouts were calculated, a cross-table of behaviour and location was made (Table 2). If a hen performed one (type of) behaviour during the majority of the time in a certain location, this location was considered a 'facility'. All time in that location was then considered as 'using that facility'.

Table 2 – Percentage of total time that behaviours are performed in a certain location

Behaviour	Location							Total
	A	D	F	G	L	N	P	
AP[a]	.	0.00	0.01	0.00	0.04	.	0.00	0.05
BP	.	0.01	0.03	0.00	0.07	.	0.00	0.11
DB	.	.	.	.	0.87	.	.	0.87
DR	.	1.36	.	.	.	.	.	1.36
ES	.	.	0.00	0.00	0.06	.	0.00	0.06
FE	.	.	21.74	.	.	.	.	21.74
FL	.	0.00	0.00	0.00	0.00	0.00	0.00	0.01
FP	.	0.00	0.08	0.01	3.57	.	0.16	3.83
FR	.	0.00	0.00	0.00	0.04	.	0.00	0.05
NS	0.06	0.10	0.23	0.01	0.82	6.62	2.12	9.94
OT	.	0.00	0.00	0.00	0.06	.	0.10	0.17
PR	.	0.01	0.07	0.04	1.76	.	7.79	9.65
SC	.	0.00	0.30	0.03	24.19	.	0.00	24.51
SI	.	.	0.06	.	0.02	.	2.62	2.70
SR	.	.	0.00	.	0.01	.	0.03	0.05
ST	0.04	0.40	2.31	1.11	11.08	.	2.81	17.76
WA	0.02	0.09	0.47	0.44	5.63	0.00	0.42	7.08
WF	0.00	.	.	0.00	0.03	.	0.01	0.04
Total	0.13[b]	1.97	25.30	1.65	48.26	6.62	16.07	100.00

[a] For explanation of abbreviations see Table 1.

[b] Deviations in column or row sums are due to rounding.

When a location did not have a prevailing behaviour, only time performing behaviours with a specific need for that facility were aggregated into 'using that facility'. In the case of litter there was, besides scratching, a lot of standing and walking, because the largest part of the pen consisted of litter. However, a hen only 'needs' litter for scratching and dust bathing. The time used to move from one facility to another, and time that was not assigned to one of the facilities, was labelled as 'traffic'. For the current dataset this resulted in the following rules:

- All time in the feeding area was considered as at the 'feeder'.
- All time in the drinking area was considered as at the 'drinker'.
- Since the perch in front of the nest boxes was used only for going into the nest boxes, it was considered as part of the nest boxes.
- All time in the nest boxes was considered as in the 'nest'.
- All time on the perches was considered as on the 'perch' (the prevailing behaviours on the perch, preening, standing and sitting, are stationary behaviours that hens (probably) prefer to perform on the perch).
- All time on the grid was considered as 'traffic'.
- Scratching and dust bathing are behaviours with a specific need for litter. Therefore, they were aggregated as in the 'litter', when hens performed these behaviours in the litter area. Other behaviours in the litter area were aggregated as 'traffic'.
- The first and last behavioural occurrence within a facility was also considered as 'traffic', except when it was the prevailing behaviour for the facility (feeding for feeder, drinking for drinker, not seen for nest, preening for perch, or scratching and dust bathing for litter).

2.4.2. *Facility utilisation*

In order to validate the simulation model with data from the second dataset, these data should be aggregated in a similar way as the data from the behavioural observations. For scan sampling data, however, it was not possible to determine the next behaviour and location, because the behaviour between the scans is not known. Therefore, we considered all moving in the feeding and drinking area as 'traffic' and all scratching and dust bathing, thus also scratching in the feeding area, as 'litter'.

2.5. *Modelling*

2.5.1. *Model input*

Input parameters were derived from the behavioural observations. Table 3 shows a simplified transition matrix with the probabilities of transitions from one facility to another. This table shows that direct transitions between facilities, however, in the simulation model traffic were included between all facilities. Table 4 shows the probability density functions of durations for each facility. Probability density functions were fitted with a free choice of type of distribution and the possibility to shift the distribution using a tool provided by the simulation software (Incontrol Simulation Software, 1997). As hens sat in the nests when lights turned on in the morning, in the model all hens started in the nest.

2.5.2. *Model structure*

Fig. 2 shows a flow chart of the simulation program. Traffic connects the five facilities—drinker, feeder, litter, nest and

Table 3 – Transition matrix with probabilities of transition (%) from one facility to another

Current facility	Next facility				
	Drinker	Feeder	Litter	Nests	Perches
Drinker	7.8	19.6	68.5	2.2	1.9
Feeder	5.7	37.7	52.5 [a]	0.7	3.4
Litter	5.7	33.1 [b]	54.5	0.6	6.1
Nests	7.8	45.4	36.4	10.4	0
Perches	6.1	20.4	68.8	1.0	3.7

Most transitions contain traffic as intermediate behaviour, with the exception of some transitions between feeder and litter v.v.

[a] Contains 2.7% of direct transition from feeder to litter without traffic as intermediate behaviour.

[b] Contains 1.6% of direct transition from litter to feeder without traffic as intermediate behaviour.

Table 4 – List of distribution functions of durations (s) as used in the model

Facility	Function	*n*
Drinker (D)	(0.24+Beta(36.64,0.90,4.30))	464
DD[a]	(2.08+Gamma(31.35,0.70))	36
DF	(5.72+Negexp(15.93))	91
DL	(2.12+Lognormal(16.32,34.28))	318
DN	66.54	10
DP	48.42	9
Feeder (F)	(0.08+Weibull(85.84,0.50))	2643
FD	(3.56+Lognormal(26.71,35.97))	150
FF	(1.04+Lognormal(20.44,46.25))	997
FL	(0.36+Lognormal(21.15,61.79))	1315
FN	87.60	18
FP	(1.84+Weibull(37.77,0.90))	91
Litter (L)	(0.08+Weibull(52.56,0.60))	4375
LD	(3.04+Lognormal(26.75,44.71))	250
LF	(0.64+Lognormal(25.36,72.22))	1375
LL	(1.36+Pearsont5(39.61,2.40))	2384
LN	(9.48+Erlang(43.07,2.00))	25
LP	(1.08+Lognormal(37.49,81.99))	267
Nests (N)	(14.12+Weibull(980.06,0.60))	62
ND	21.10	6
NF	(6.00+Lognormal(12.89,17.87))	35
NL	(6.76+Gamma(36.53,0.30))	28
NN	46.33	8
NP	xxx	0
Perches (P)	(0.80+Beta(384.28,0.50,2.20))	378
PD	(6.76+Lognormal(17.96,33.49))	23
PF	(3.44+Lognormal(23.36,47.51))	77
PL	(1.40+Lognormal(19.68,42.63))	260
PN	63.06	4
PP	26.34	14

The last column gives the number of data points used for fitting the functions. When $n<20$ the arithmetic mean was used instead of a fitted function.

[a] Codes with double letters are ‘traffic’, with the first letter being the previous facility and the second letter the next facility.

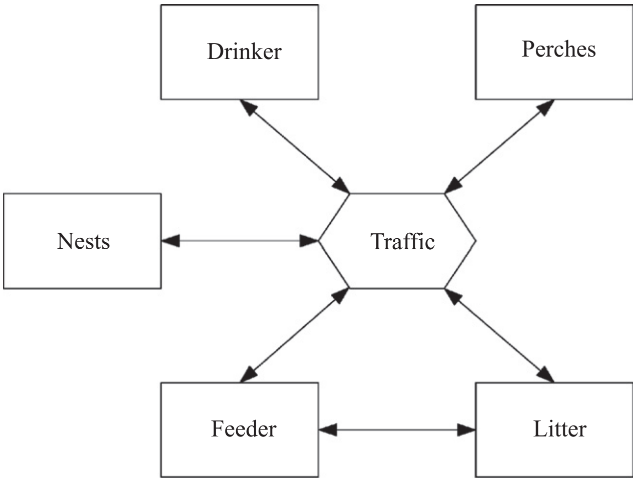

Fig. 2 – Flow chart of the simulation program. Traffic connects the five facilities—drinker, feeder, litter, nest and perch—with each other. Only litter and feeder are connected directly, which means that a transition without traffic is possible (e.g. scratching starts in the feeder area and continues in the litter area).

perch—with each other. Only litter and feeder are connected directly, which means that a transition without traffic is possible (e.g. scratching starts in the feeder area and continues in the litter area).

The software package Enterprise Dynamics (ED; Incontrol Simulation Software, 1997) was used for the simulations in this study. In the world-view of ED, a model consists of permanent and temporary elements. Permanent elements, like servers and queues, are connected and form a so-called network. Servers represent the facilities. Single servers can serve one element at a time, whereas multi-servers are able to serve more elements simultaneously (with a predefined maximum). Queues become important when the capacity of facilities is limited. Temporary elements—in this system, laying hens—flow through the network of the permanent elements. When a hen uses a facility, for example the feeder, the hen enters the server ‘feeder’, where it stays for a certain time. The duration of the stay is drawn from a distribution function, which is derived from the behavioural observations (Table 4). After the time has elapsed, the hen leaves the server and goes to another server (facility). The probability that a hen visits a facility after another one (or returns to the same facility) is read from the transition matrix, which is also derived from the behavioural observations (Table 3).

Five multi-servers represented the facilities drinker, feeder, litter, nest and perch. Furthermore, 25 multi-servers represented ‘traffic’. All ‘traffic’ was split into 25 groups by its preceding and following facility, e.g. ‘traffic’ between ‘feeder’ and ‘drinker’ was referred to as FD.

2.5.3. *Model output*

The developed model is a stochastic model. To obtain statistically reliable results from a stochastic model, many runs have to be performed. Visual observation of the running means of the output parameters can be used to determine the number of runs necessary to conduct a reliable experiment.

During test runs we determined that above 500–600 runs the running means were rather constant. To be safe, we chose to make 1000 runs for each simulation.

The most important model output was the average utilisation of the facilities. This is one of the outputs the model calculates. As long as ample facilities are available, average utilisation is a good indicator of model performance. When the availability of facilities is reduced, it also becomes important to know how often a facility is used at maximum capacity (maximum number of hens using a facility at the same time). Therefore, histograms of facility utilisation were also made.

2.6. *Verification and validation*

2.6.1. *Verification*

The dataset resulting from the behavioural observations can be used for verification. Based on the behavioural records, we calculated the proportion of time a hen uses the different facilities. The average percentage of time multiplied by 8 (the number of hens) results in the number of hens at a certain facility, i.e. the facility utilisation.

2.6.2. *Validation*

The dataset concerning facility utilisation was used for validation. As instantaneous scan sampling was used to collect these data, the average facility utilisation was calculated as the average result of the scans. Furthermore, counts of hens using a certain facility at a time were obtained, resulting in histograms of facility utilisation. These data were compared to the model output, as described in the preceding section.

2.7. *Sensitivity analysis*

Another way of testing the model, besides validation, is a sensitivity analysis. In this study we tested three options for varying model settings and compared them all to the basic model settings.

(1) As one of the basic assumptions of continuous time Markov chains is that the probability of a transition between states is independent of the time the current state has already endured, the distribution functions have to be negative exponential functions. In order to test this property, we tested the influence of using negative exponential distribution functions instead of the best-fitting distribution functions for all functions in Table 4. This option is referred to as ‘exponential distributions’.
(2) In the morning, all hens were in the nest boxes. When the light was turned on, they came out of the nests quickly. In the basic settings, the time animals stayed in the nests after starting the simulation was taken from the distribution function as shown in Table 4. We tested the influence of using the average time the hens stayed there in practice (129.94 s) instead. This option is referred to as ‘nest stay’.
(3) Laying hen behaviour shows diurnal patterns (Lee and Chen, 2007; Savory, 1980). In order to incorporate this into the simulation model, we calculated different transition matrices for blocks of 4 h (data not shown) and incorporated them into the model, in order to influence the probability of using a certain facility. The distribution functions were not changed. This option is referred to as ‘diurnal rhythm’.

3. Results and discussion

3.1. *Verification and validation*

3.1.1. *Facility utilisation*

One of the important model outputs is the facility utilisation, as this shows whether the hens are able to perform the behaviour they prefer. This will not lead to a problem under the current conditions, since ample facilities were provided, both in practice as well as in the simulation model. Table 5 shows the facility utilisation based on the two datasets and on the simulation model. For verification the column named ‘behavioural observations’ has to be compared to the column ‘basic simulation’. This shows that the model approaches these data very well, except for the nest use. Although the deviation in nest use is still less than one standard deviation, it will be discussed as the second option in the sensitivity analysis.

For model validation, however, it is necessary to compare the facility utilisation as produced by the simulation model to data from the validation dataset. These data are shown in Table 5, ‘facility utilisation’. This shows deviations larger than the standard deviation for feeder, perch and traffic. These deviations could be due to changing needs of the hens while ageing, represented in two datasets that were successively collected, but there are also some other possible explanations.

The underestimation of feeder utilisation by the simulation model compared to the validation data (facility utilisation) may be due to the fact that the observers had a different perception of the feeder area. Hens standing at some distance from the feeder were scored as in the litter area during behavioural observations, which was regarded as ‘traffic’ in the processed data and in the simulation model. During observations of facility utilisation these hens would have been scored as in the feeder area, which was regarded as

Table 5 – Average number of hens (standard deviation) at each facility during the 16 h light period based on both datasets and the simulation model

Facility	Behavioural observations	Basic simulation	Facility utilisation
Drinker	0.15	0.15 (0.01)	0.15
Feeder	1.99	1.94 (0.12)	2.57
Litter	2.01	1.97 (0.09)	2.06
Nests	0.54	0.70 (0.19)	0.58
Perches	1.27	1.24 (0.12)	1.04
Traffic	2.04	2.00 (0.08)	1.61
Total	8	8	8

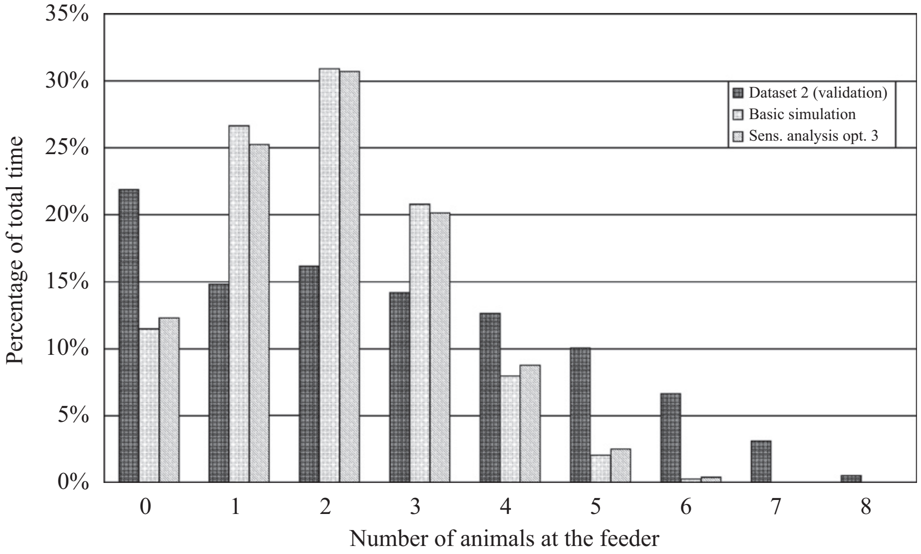

Fig. 3 – Histograms of the number of hens at the feeder in the validation dataset, in the basic simulation and in the third option of the sensitivity analysis testing the influence of a diurnal rhythm (basic simulation: 1 run of 80 h; Sensitivity analysis option 3: 5 runs of 16 h).

Table 6 – Average number of hens (standard deviation) at each facility during the 16 h light period based on the simulation model with different settings

Facility	Basic simulation	Exponential distributions	Nest stay	Diurnal rhythm
Drinker	0.15 (0.01)	0.15 (0.01)	0.15 (0.01)	0.14 (0.01)
Feeder	1.94 (0.12)	1.95 (0.08)	1.95 (0.12)	1.91 (0.13)
Litter	1.97 (0.09)	1.97 (0.07)	1.99 (0.10)	1.88 (0.11)
Nests	0.70 (0.19)	0.70 (0.14)	0.63 (0.20)	0.86 (0.24)
Perches	1.24 (0.12)	1.23 (0.11)	1.26 (0.12)	1.23 (0.12)
Traffic	2.00 (0.08)	2.00 (0.06)	2.02 (0.09)	1.97 (0.10)
Total	8	8	8	8

For explanation of the different settings see Section 2.7 Sensitivity analysis.

'feeder' in the processed data. This corresponds with an overestimation of traffic.

Overestimation of perch utilisation by the simulation model may be due to ageing of the hens in the validation dataset. A similar result was found by Appleby and Duncan (1989). They noticed that birds that were used to perching continued to perch, but for diminishing amounts of time after the start of lay (weeks 21/22 compared to weeks 26/27).

3.1.2. *Facility occupancy*

The black and grey bars in Fig. 3 show the histograms of the number of hens at the feeder in the validation dataset and the simulation. The main similarity can be found in the fact that both distributions have a peak at $n = 2$. In the validation dataset, however, another, and even larger, peak occurs at $n = 0$, which is not present in the simulation data. Furthermore, the validation dataset shows a higher percentage of time with four hens or more at the feeder. Both dissimilarities may point to the presence of group behaviour, causing more incidences of many hens at the feeder, but also more time with no hens at the feeder. These results indicate that group behaviour is an important aspect to include in future models. This is supported by the literature on social facilitation of feeding behaviour (e.g. Meunier-Salaün and Faure, 1984; Tolman and Wilson, 1965; Keeling and Hurnik, 1993). Inclusion of group behaviour was not possible within the current study, because input data (behavioural observations) were not suitable for this purpose, as every day only one out of eight hens was observed.

3.2. *Sensitivity analysis*

In this study we tested three options during the sensitivity analysis. All options are compared to the basic simulation on facility utilisation (Table 6). The third option is also compared on facility occupancy (Fig. 3).

3.2.1. *Facility utilisation*

The first option, testing the influence of using negative exponential distribution functions instead of the best-fitting distribution functions, shows that this hardly affects the final facility utilisation (Table 6). This is supported by Hillen (1993), who states that to represent collected data by a distribution function, it is more important to select the correct mean than the correct family of the function. It seems that, as long as the average duration of stay at a facility is correct, the final facility utilisation is predicted similarly. This supports the assumption that the records of facility utilisation used can be considered as continuous time Markov chains.

The second option, testing the influence of time hens stayed in the nests after starting the simulation, only shows a noticeable effect on nesting (Table 6). These results approach the behavioural observations (Table 5) better than the basic simulation, indicating that the model was improved by adapting the starting values of the model.

The third option, testing the influence of the diurnal rhythm, shows a remarkable increase in nesting behaviour (Table 6). This, however, may be due to a peculiarity in the data, because the hens entered the nests at the end of the observation period (dim light period) and did not leave the nests anymore. Therefore, during the last four hours of the simulation, a hen could not get out of the nest anymore when once inside.

3.2.2. *Facility occupancy*

The shaded bars in Fig. 3 show the results of the third option of the sensitivity analysis testing the influence of the diurnal rhythm. Results are very similar to the grey bars, but show a slight adjustment towards the validation data (black bars). This means that the sensitivity of the model for four different transition matrices is low. This could be due to the rather coarse method of adjustment. Smoother methods, using (curvi-)linear adjustments of transition matrices and distribution functions, may result in higher sensitivity of the model. It, however, will remain questionable whether such adjustments will improve the model enough to approach the validation data. The already mentioned influence of group activities will probably override these settings. This means that future models must be able to account for group behaviour.

4. Conclusions

The first step of this study was to show that it is possible to model results from behavioural observations with a discrete-event simulation model. We realised this by transforming the behavioural elements into bouts of certain behaviours, and, subsequently, allocating behaviour to a certain facility. Next to using the facilities, we also allocated time for ‘traffic’, in order to give the opportunity to move to another facility and perform some behaviours that are not bound to a certain facility. After these data handling steps, it was clearly possible to simulate facility demand with a discrete-event model.

The second step of this study was to validate the model results with data on facility utilisation from a different dataset. Furthermore, we also performed three options in a sensitivity analysis. In general, the results were promising; however, some points need future attention. An aspect that certainly needs attention is the possibility to include group behaviour, because results on occupancy of facilities showed that this is necessary.

In conclusion, discrete-event modelling is a potential tool to estimate facility demand of laying hens over the complete day.

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REFERENCES

Albentosa M J; Cooper J J (2004). Effects of cage height and stocking density on the frequency of comfort behaviours performed by laying hens housed in furnished cages. Animal Welfare, **13**(4), 419–424

Animal Sciences Group (2006). Welfare implications of changes in production systems for laying hens; Deliverable 2.3 Description of housing systems for Laying hens. June 11, 2007 〈http://www.laywel.eu/web/pdf/deliverable%2023.pdf〉

Appleby M C; Duncan I J H (1989). Development of perching in hens. Biology of behaviour, **14**(2), 157–168

Banks J; Carson II J S; Nelson B L; Nicol D M (2001). Discrete-event System Simulation, 3rd edn. Prentice-Hall, Englewood Cliffs, NJ

Cooper J J; Appleby M C (2003). The value of environmental resources to domestic hens: A comparison of the work-rate for food and for nests as function of time. Animal Welfare, **12**(1), 39–52

EC (1999). Council Directive 1999/74/EC of 19 July 1999 laying down minimum standards for the protection of laying hens. Official Journal of the European Communities, **L203,** 53–57

Haccou P; Meelis E (1992). Statistical Analysis of Behavioural Data: An Approach Based on Time-structured Models. Oxford University Press, Oxford, UK

Halachmi I (2000). Designing the optimal robotic milking barn, part 2: Behaviour-based simulation. Journal of Agricultural and Engineering Research, **77**(1), 67–79

Hillen D W (1993). Simulatie in Productie en Logistiek. Academic Service, Schoonhoven, The Netherlands (in Dutch)

Incontrol Simulation Software (1997). Enterprise Dynamics. Incontrol Simulation Software B.V., Maarssen, The Netherlands

Keeling L J; Hurnik J F (1993). Chickens show socially facilitated feeding behaviour in response to a video image of a conspecific. Applied Animal Behaviour Science, **36**(2–3), 223–231

Kettenis D L (1997). An algorithm for parallel combined continuous and discrete-event simulation. Simulation Practice and Theory, **5**(2), 167–184

Law A M; Kelton W D (2000). Simulation Modeling and Analysis. McGraw-Hill, Boston

Lee Y P; Chen T L (2007). Daytime behavioural patterns of slow-growing chickens in deep-litter pens with perches. British Poultry Science, **48**(2), 113–120

Martin P; Bateson P (1993). Measuring Behaviour: An Introductory Guide, 2nd edn. Cambridge University Press, Cambridge, UK

Metz H A J; Dienske H; de Jonge G; Putters F A (1983). Continuous-time markov chains as models for animal behaviour. Bulletin of Mathematical Biology, **45**(4), 643–658

Metz J H M (1975). Time patterns of feeding and rumination in domestic cattle. PhD Thesis, Agricultural University, Wageningen, The Netherlands

Meunier-Salaün M C; Faure J M (1984). On the feeding and social behaviour of the laying hen. Applied Animal Behaviour Science, **13**(1–2), 129–141

Mollenhorst H; de Boer I J M (2004). Identifying sustainability issues using participatory SWOT analysis-A case study of egg production in the Netherlands. Outlook on Agriculture, **33**(4), 267–276

Olsson I A S; Keeling L J (2002). The push-door for measuring motivation in hens: Laying hens are motivated to perch at night. Animal Welfare, **11**(1), 11–19

Pidd M (1992). Computer Simulation in Management Science. Wiley, Chichester

Savory C J (1980). Diurnal feeding patterns in domestic fowls: a review. Applied Animal Ethology, **6**(1), 71–82

Sibly R M; Nott H M R; Fletcher D J (1990). Splitting behaviour into bouts. Animal Behaviour, **39,** 63–69

Slater P J B; Lester N P (1982). Minimising errors in splitting behaviour into bouts. Behaviour, **79,** 153–161

Tolkamp B J; Nielsen B L; Kyriazakis I; Allcroft D J; Austin E J (1998). Satiety splits feeding behaviour into bouts. Journal of Theoretical Biology, **194**(2), 235–250

Tolman C W; Wilson G F (1965). Social feeding in domestic chicks. Animal Behaviour, **13**(1), 134–142

Wechsler B (2007). Normal behaviour as a basis for animal welfare assessment. Animal Welfare, **16,** 107–110

Weeks C A; Nicol C J (2006). Behavioural needs, priorities and preferences of laying hens. World's Poultry Science Journal, **62**(2), 296–307