Daily Management Support in Aviary Housing Systems for Laying Hens

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Daily Management Support in Aviary Housing Systems for Laying Hens

C. Lokhorst

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Determining the goals, critical success factors and information needs of poultry farmers working with aviary systems for laying hens reveals that support of the day-to-day management should aim to control the feed consumption and the ambient house temperature, and to detect diseases early. An Egg Weighing And Counting System (EWACS) is developed to count and weigh the eggs in groups of laying nests, and an Individual Poultry Weighing System (IPWS) is developed to measure the body weights and the flock-uniformity of groups of hens. These data are used to ascertain how, where and when the mean body weight, the number of eggs produced and the mean egg weight of a flock of hens must be determined, to supply reliable information for supporting the daily management. A decision support system (DSS) is developed to support the daily management. It contains mathematical curves describing several input and output variables of the production process. The curves can be made farm-specific and can be used as a flock-specific standard in the expert system (ES) incorporated in the DSS. The ES can be used to monitor the daily production process in aviary systems and it uses quantitative and qualitative data to detect aberrations in feed consumption, to control the ambient house temperature and to detect disease.

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Stellingen

1. Door uit te gaan van de kritische succesfactoren: voeropname, staltemperatuur en tijdige opsporing van ziektes en door gebruik te maken van dagelijkse in plaats van wekelijkse produktiegegevens beschikt de pluimveehouder over de belangrijkste middelen om het produktieproces in volièrestallen voor leghennen te beheersen.
   Dit proefschrift

2. Het ter beschikking hebben van (geautomatiseerde) monitoringsystemen stelt de pluimveehouder in staat beter te voldoen aan het algemeen geldende voorschrift om dagelijks zijn kippen te inspecteren.
   Dit proefschrift; Beschikking legbatterijen

3. Voor het beoordelen van de gebruiksmogelijkheden van geautomatiseerde dierweegsystemen voor pluimvee is het gebruik van individuele dierherkenning met behulp van transponders voorwaarde.
   Dit proefschrift

4. Land- en tuinbouwbedrijven zijn dermate afhankelijk geworden van nutsbedrijven dat aangeraden moet worden om eigen noodvoorzieningen te treffen.

5. Veel eerder dan economische zullen politieke keuzes ervoor moeten zorgen dat het marktaandeel van produkten die geproduceerd zijn in welzijnsvriendelijke huisvestingssystemen toeneemt.

6. Het succes van op techniek gebaseerde oplossingen in de huisvesting en houderij ter bevordering van het welzijn van landbouwhuisdieren wordt in toenemende mate bepaald door het aanpassingsvermogen van deze dieren.

7. Omdat mensen onvoldoende in staat zijn om niet lineaire processen te doorzien worden neurale netwerken met voordeel toegepast bij de beheersing van produktieprocessen in de land- en tuinbouw.

8. Vele, op ad hoc beleid gebaseerde milieu- en welzijnsmaatregelen zijn onvoldoende getoetst op hun gevolgen voor mens en dier.

9. '... in real life mistakes are likely to be irrevocable. Computer simulation, however, makes it economical practical to make mistakes on purpose. If you are astute, therefore, you can learn much more than they cost. Furthermore, if you are at all discreet, no one but you need know you made a mistake.'
   H.H. Pattee et al., 1966. Natural automata and usefull simulations, McMillan, London

10. Een duurzame landbouw vereist managers met een (informatie)technologisch hart en een ecologische ziel.

C. Lokhorst
Daily Management Support in Aviary Housing Systems for Laying Hens
31 Mei 1996, Wageningen.

'.. and each new problem would require a new crusade, and each new crusade would leave fresh problems for yet further crusades to solve and multiply in the good old way..'
(Aldous Huxley, Time must have a stop)

Voor Angelique, Tamara, Jessica en Nynke

VOORWOORD

Om een lang verhaal kort te houden heb je als promovendus onmiskenbaar de hulp nodig van je directe begeleiders. Voor de goede adviezen, de wijze lessen en het (her)lezen en beoordelen van mijn concepten bedank ik prof. dr ir L. Speelman, prof. dr ir W. de Wit en dr ir J.H.M. Metz. De heren ing. R.K. Oving, dr Ir H.W. Vos en ing. J. Frederiks bedank ik voor hun enthousiasme en de energie die zij de eerste twee jaar in het onderzoek gestoken hebben. Prof. dr ir M.W.A. Verstegen ben ik dankbaar voor de eye-opener die hij heeft gegeven voor de rapportage over de ontwikkelde mathematische curves.

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Kees Lokhorst

CONTENTS

Chapter 1

General Introduction

General introduction

1. Scope and objectives of the thesis

Management in aviary systems differs from management in cage systems for laying hens and is more complex (COVP,1987; Elson, 1992; Meierhans, 1992). Aviary housing systems have been developed to benefit the welfare of laying hens and to provide, as good as possible, an economically viable alternative to cage systems (Blokhuis and Metz, 1992, 1995). An aviary system is basically a traditional floor housing system with extra tiers of slats or wire to increase the use of vertical space in the house (Appleby et al., 1992). In aviary systems there is an area of approximately 1000 cm^2 available per hen, the hens have freedom of movement, they can scratch and dustbath in the litter on the floor, and they can roost on perches and lay eggs in nests. Prototypes of aviary systems have been described by Ehlhardt *et al.* (1988), Appleby *et al.* (1992) and Blokhuis and Metz (1995).

The cost price of eggs produced in aviary systems is still 7-15 % higher than that of eggs produced in cage systems (Elson, 1989,1992; Van Horne, 1991; Meierhans, 1992; Blokhuis and Metz, 1995). A higher feed consumption, higher housing costs and more variation in the production results have been identified as important factors (Van Horne,1991). There is also a higher risk of diseases in aviary systems, since hens have more contact with their droppings (litter). There is also more contact between different hens, since they have the freedom to move around. In floor-housed flocks, like aviaries, there is a higher risk of infectious disease, endo-parasites (round and flat worms), ecto-parasites (mites), pathological conditions of the feet and cannibalism (Appleby *et al.*,1994).

The poultry farmer needs to know what is going on in the aviary house, in order to be able to control the cost price and the variation in the production process. It can be expected that a good registration and analysis of production and health data will help in the identification of deviating production circumstances, such as diseases, at an early stage. Then measures can be taken in time, in order to minimise potential losses of production (Buckett, 1988). When weekly reports are used, which is common practice, the information is too general and action time to solve potential problems in the production process is lost (ATC, 1994). Recent technological progress in computer hard- and software and a rapid decline in the costs of computers have increased the opportunities for effective computer-based daily support of farm management (King *et al.*, 1990; Day, 1991; Lanna & Streeter, 1994). Earlier Belyavin (1988) pointed out that the poultry sector is ideally suited to computer technology, because of technological innovations and the increase in scale of poultry farms.

The modern poultry farmer needs to be supported daily by effective management tools. The research described in this thesis aims to provide that support. Its objective is:

> **To support the poultry farmer in his day-to-day management by improving the control of the production process in aviary housing systems for laying hens on the basis of data collected daily.**

Three general questions arise from the objective. The management needed to control the daily production process in aviary housing systems has to be well defined. This raises the question:

- Is it possible to give a description of the daily management needed to control the production process in aviary systems for laying hens?

The next step is to describe the information needed. Because aviary systems are relatively new, not much is known about the measurement equipment or about the characteristics of the data gathered. This raises the next question:

- What are the characteristics, e.g. accuracy, of data measured daily in aviary systems and what reliable information can be generated from these data ?

The third step is to connect the daily information from the production process to the management tools that support the poultry farmer in controlling the production process. Therefore, the third research question is:

- What management tools can be developed to support the daily management to control the production process in aviary systems for laying hens ?

2. Background

In the eighties social and political pressure on the poultry sector in some West European countries increased, aiming at the improvement of the welfare of laying hens in intensive housing systems, which led to the development of alternative housing systems for laying hens (Blokhuis & Metz, 1992). In Western Europe, a substantial amount of research has been done on developing alternative housing systems for laying hens (Ehlhardt *et al.*, 1988; Elson, 1989; Kuit *et al.*, 1989; Meierhans, 1992; Wegner, 1992).

At the end of the eighties legislation was drafted in the Netherlands in which it was foreseen that cage systems would be banned by July 2004 and that after July 1994 no cage systems older than 10 years should be in use. At the same time the research programme 'Development and practice testing of aviary housing systems for laying hens' was set up by the DLO Institute for Animal Science and Health (ID-DLO) and the DLO Institute of Agricultural and Environmental Engineering (IMAG-DLO). Other research partners were the DLO Agricultural Economics Research Institute (LEI-DLO), the National Reference Centre for Agriculture - Division of Poultry Production (IKC-Pluimveehouderij) and the Health Service for Poultry (GvP). The research programme started in 1990 and lasted four years. Its main objective was to develop a poultry housing system, that takes account of the increasing requirements on animal welfare and the environment and that complies with the technical requirements of modern management and adequate labour conditions for the poultry farmer. An integrated approach combining different research specialities was used in the research programme. The research presented in this thesis was conducted as part of that research programme.

3. Outline of this thesis

Chapters 1 and 2, comprise a general introduction and definition of daily management in aviary systems for laying hens. The farmers goals, critical success factors, information needs, a management concept and the need for management support are described.

Chapters 3, 4, and 5 are dealing with the methods and the accuracy of measuring daily production variables in aviary systems. Chapter 3 describes the development of an Egg

Weighing and Counting System (EWACS), which enables the number of eggs and the mean egg weight of individual or groups of laying nests within an aviary house to be measured daily. EWACS was used for a detailed analysis of the egg production within an aviary system, as is described in chapter 4. The accuracy of the variables body weight and flock uniformity within an aviary system for laying hens were studied using the Individual Poultry Weighing System (IPWS). The results of this experiment are described in chapter 5.

Next attention is paid to the development of specific management tools that support the monitoring process of three critical success factor areas. In chapter 6 a set of mathematical curves is described which can be used as a standard in an expert system (ES). Ten mathematical curves for different input and output variables of the production process are described. In chapter 7 the development and the validation of an ES is described. The ES can be used for the daily monitoring of the production process.

A general discussion of the research results, together with the conclusions and the need for future research are described in chapter 8.

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Chapter 2

Management support in aviaries for laying hens: goals, critical success factors, information needs, a management concept and management tools

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C. Lokhorst, J.H.M. Metz, L. Speelman, W. de Wit

Abstract

Aviary housing systems have been developed to improve the welfare of laying hens, but they require an other management than cage systems. To reduce the difference in cost-price between eggs produced in aviary systems and cage systems and to control the variation in the production circumstances, adequate tools to support daily management are needed. This paper describes the aviary farmer's goals, critical success factors, information needs, and the selection of an appropriate management concept. The aviary farmer's goals are 1) the efficient production of high quality eggs, 2) a welfare friendly treatment of the hens, and 3) a long-term profitability of the farm. The control of feed consumption, ambient temperature and the early detection of diseases are the three main critical success factors. Timely and reliable information is needed on feed consumption, egg-production and diseases per group of hens or per compartment in an aviary system. The Poultry Information Model was adopted as a suitable management concept. An analysis of the daily management functions 'operational planning', 'implementation' and 'operational control' for three critical success factors resulted in the recommendation of management tools for the function of 'operational-control'.

1. Introduction

Modern poultry production is characterised by large flocks and high investments in buildings and equipment (Renkema, 1992). The number of egg-producing farms in the Netherlands decreased with 48 % since 1980 to 3241 farms in 1993. In the same period the total number of hens increased 12 % to 29.8 million hens in 1993 (CBS,1993). More than 70 % of the hens are housed on 15 % of the farms and these farms have more than 20.000 hens (NN,1993).

The welfare of poultry has become an important issue in the last 30 years (Harrison, 1964; Elson, 1989; Appleby *et al*, 1992; Blokhuis & Metz, 1992; Blokhuis & de Wit, 1992; De Wit, 1992). Social and political pressure were the main reasons for developing alternative housing systems for the cage system (Appleby *et al*,1992). In the Netherlands aviary housing systems for flocks of 15.000-25.000 hens are built as a welfare friendly alternative for the still widespread cage system (Blokhuis & Metz,1992). An aviary system is basically a traditional floor housing system with extra tiers of slats or wire to increase the use of the vertical space in the house (Appleby *et al*, 1992). A stocking density of 20-25 birds per m^2 floor area can be attained, which is comparable with the stocking density of a three-tiered cage system. Traditional floor systems usually have less than 7 birds per m^2 floor area.

Income margins on poultry farms are small and thus income is extremely susceptible to deficient technical input/output ratios and to a drop in the price of eggs (Renkema, 1992).

Consequently, poultry farmers are trying to decrease risk and to find ways of increasing the ratio between production value and production costs. The cost price of eggs produced in aviary systems is 8-15 % higher than that of eggs produced in cage systems (Elson, 1989,1992; Meierhans *et al*, 1992). Van Horne (1991) found a 7-12 % higher cost price for the Tiered Wired Floor (TWF) aviary system (20 hens/m^2 floor area). A greater feed consumption, higher housing costs and an increased risk of more variation in the production results were important factors responsible for the higher cost price in aviary systems.

Management, which is the decision-making process in which limited resources are allocated to several production alternatives so that goals and objectives are attained, is a complex and difficult task because it takes place in a risky and uncertain environment (Kay, 1986; Huirne, 1990). Management in aviary systems differs and sometimes is found to be more complex than management in cage systems because hens are housed in large groups and have more freedom to move (Elson, 1992; Meierhans, 1992). Furthermore, hens in aviary systems have more contact with their droppings (litter), which increases the risk of a fast spread of infectious diseases, bumble foot, worm infections and red mites (Appleby *et al*, 1994; Bosch & Niekerk, 1995). Eggs laid on the floor or on the tiers cause much extra labour and there is an increased risk of second grade eggs. Flock dynamics also can cause severe problems. If too many hens accumulate, they die from suffocation. In an aviary system the poultry farmer has to walk through the hens during the obligatory daily inspection, so there is a different interaction between the poultry farmer and the hens, which can result in other information from the flock than in cage systems.

According to Ziggers and Bots (1989) there is a correlation between negative financial results and complex decision situations; they concluded that financial results could be improved by the use of management tools that improve the quality of the decisions. Sainsbury (1992) found that successful farms are those that react quickly to any risk or appearance of diseases. Based on the findings of Ziggers and Bots (1989) and Sainsbury (1992) one can conclude that effective management tools are necessary for controlling the decision situations in aviary systems for laying hens.

Recent technological progress in computer hardware and software and a rapid decline in the costs of computers have increased the opportunities for effective computer-based support of farm management (Day, 1991; King *et al*, 1990; Lanna & Streeter, 1994). Belyavin (1988) concludes that the poultry sector is ideally suited to use computer technology, because of the intensification of poultry farms.

The main goal of our study is to develop computer-based management tools for the aviary farmer, to enable him to plan and control the complex production process based on an optimal use of daily data. This paper describes the aviary farmer's goals, critical success factors and information needs and the selection of an appropriate management concept. It also analyses the daily management functions operational planning, implementation and operational control for three critical success factors and an advice is given to develop management tools to support daily management in aviary farms for laying hens.

2. Goals, critical success factors and information needs

Before tools that support daily management can be developed, the goals, critical success factors and information needs to support these critical success factors are determined. Comparable results of Huirne *et al.* (1993), which were obtained by using workshop and interview techniques, from pig and dairy farms were used together with a literature research and discussions with poultry experts, to determine the goals, critical success factors and information needs for aviary poultry farms (Table 1).

Table 1 Goals, critical success factors and information needs for aviary housing systems for laying hens.

Goals
1 efficient production of high quality eggs
2 optimal (welfare friendly) treatment of hens
3 long-term profitability
Critical Success Factors
1 control of feed consumption
2 control of ambient temperature
3 early detection of diseases
Information needs
1 fast and up-to-date data on feed consumption, diseases and production results
2 detailed daily information per group of hens or per compartment

2.1 Goals

The most important goals on pig and dairy farms are 1) the efficient production of meat c.q. milk, 2) the realization of optimal technical results and 3) to ensure the long-term profitability of the farm (Huirne et al., 1993). For pig farms the fourth goal was the production of high quality products, but for dairy farms the fourth goal was the optimal treatment of the animals (Huirne et al., 1993). Important goals for aviary farms of laying hens are 1) the efficient production of high quality eggs, 2) an optimal treatment of the hens (for their welfare), and 3) a long-term profitability of the farm. Efficient production in this case means the realization of optimal technical production results against low costs. High quality eggs in aviary farms mean a low percentage of floor eggs and a low percentage of second grade eggs.

2.2 Critical success factors

The critical success factors for production management on pig and dairy farms were disease control, oestrus detection and feed cost control. Control of the feed consumption, control of the ambient temperature and disease control are important critical success factors on aviary farms. Feed costs amount to 60-70 % of the total production costs and they are partly responsible for the difference between the cost price of eggs from aviary systems and cage systems (Van Horne, 1991; Luiting, 1991; Renkema, 1992).

The control of the ambient temperature in the aviary house is of interest, because egg production and feed- and water consumption are related to the ambient temperature (Belyavin,1991; Van Kampen, 1984; Marsden & Morris, 1987). With an increasing ambient temperature between 10°C and 30°C, the feed consumption decreases more than the egg production (Van Kampen, 1981; Marsden *et al.*, 1987). Marsden and Morris (1987) calculated that energy available for egg production was maximal at 23 °C for brown hens and maximal at 24 °C for white hens.

Early detection of diseases and disease control is also a critical success factor (Keirs *et al*, 1991; Blokhuis & Metz, 1992; Sainsbury, 1992; Rives, 1993). The spread of diseases in an aviary system can differ from a cage system. In a cage system the only contact between hens is limited to hens in adjacent cages. Bosch and Niekerk (1995) recorded disease data from 24 flocks in aviary systems. In six of the 24 flocks a decrease in the production results was found. The main cause was an E-coli infection. Because the farmers followed a strict protocol to monitor diseases, and because blood and faeces were checked regularly, treatments were also given to 17 flocks that showed no decrease in production results. Most of these preventive treatments concerned worm infections (15/24) and louses (14/24). These results show that the poultry farmers use more information besides the production results. No data on treatment and disease were available for cage systems, so a good comparison was impossible. Appleby *et al* (1994) stressed that, compared to cage systems, there is a higher risk in floor-housed flocks of infectious diseases, endo- and ecto-parasitism, pathological conditions of the feet and problems caused by atmospheric contamination, both dust and noxious gases. In cage systems, however, there is a higher risk of fatty livers and osteoporosis.

2.3 Information needs

Information is needed to reach the farmer's goals and to control the critical success factors. The effectiveness and the efficiency of management can be improved by using reliable and timely information (Bots *et al*, 1990; Dean & Wellman, 1991; Devir *et al*, 1993). Information is based on data that are transferred and interpreted in the context of a specific problem (Harsh, 1978). If data are transformed into the right information, they can be used to support different decisions, but the value of information changes with time (Harsh, 1978 ;Beetley & Gifford, 1988).

Information needs concerning production management on pig and dairy farms were 1) fast and up to date information on actual and possible diseases, 2) detailed production and reproduction information on individual animals and 3) information on feed costs and rationing balancing. In the same way for aviary systems it is important to have fast and up to date information on actual feed consumption, possible diseases and production results.

A poultry farm can be build up of one or more production units. A production unit can be managed separately, and economical and technical results must be obtained per unit. The production unit under the farmer's control in aviary systems, will be a flock that is housed in the whole house or a sub-flock that is housed in a compartment. A compartment then is a physically separated part of the house. Within a compartment hens of the same age and strain are housed and they have the freedom to move around freely. The size of the production unit may differ from farm to farm. In smaller production units aberrations in the production process could cause more statistical variation in the production data. Consequently, these aberrations may be detected easier and there will be probably more time to take the right measures. All relevant data, such as egg numbers, egg weight, feed consumption, water consumption and body weight must at least be determined per production unit.

In new problem areas or husbandry systems, such as aviary systems are, it must be determined first which information can be gathered and what this information conveys about the state of the production process, because the method of data collection influences the quality of information (Lanna & Streeter, 1994). Therefore, it is necessary to know the characteristics, such as averages and variation of specific variables and relations between variables in different production circumstances and in different production units.

At present, most poultry farmers send their weekly production data to their feed suppliers, who transform the data into standardised management reports. Only 10 - 15 % of the potential farms use a Personal Computer with a Management Information System (Postma,1994). The MIS on the farm performs the same tasks as the central data processing. Its main task is to register flock data and to produce weekly or four-weekly reports and graphs of the production results. Flock data are gathered daily, but are aggregated to weekly or monthly indices. This inevitably means a loss of information. When data are processed on the farm using a MIS, it becomes possible to produce daily reports, and short time aberrations in the production process can then be detected more easily. A period of 24 hours will be an appropriate time horizon for managing the poultry production process in aviary systems.

3. Management concept

A management concept is a model that describes all relevant decision-making processes of a farm and their mutual relations and it is used for better understanding the management of a farm. The choice of a management concept depends on the type of organisation and the type of problems/decisions it must be used for (Bots *et al*, 1990). To adopt a suitable management concept, one can look at 1) the internal consistency, 2) the level of detail, 3) the validity and 4) the transferability (Bots *et al*, 1990).

The management concepts of strategic, tactical and operational management (Blumenthal, 1974; Boehlje & Eidman, 1984), the Wageningen Operations Approach (Kampfraath & Marcelis, 1981), the paradigm of De Leeuw (1982), the Poultry-Information-Model (PIM) (COVP, 1986) and the model of In 't Veld (1992) are compared on the four points mentioned by Bots *et al* (1990). They are all internally consistent and valid. However, they differ in the degree of detail and the transferability. The PIM has been adopted as the management concept for aviary systems, because this model has already been introduced and accepted into the poultry sector (it is transferable) and because it describes different levels (strategic, tactical, operational management) in detail.

The PIM is a complete description of a poultry farm and it gives a representation of the decision moments (process model), the information flows and the data structure of a farm (data model). Within the PIM functions and processes are distinguished. A function is defined as a part of a farm that is coherent in the same information needs (COVP,1986). A process is a part of the function that can be executed separately. The PIM distinguishes three main functions, namely 1) strategic and tactical planning, 2) operational management and 3) evaluation, which is shown schematically in figure 1.

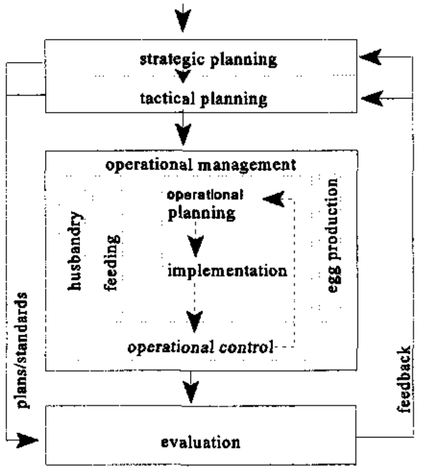

Figure 1 The management concept used in the Poultry Information Model (according to COVP, 1986).

The daily control of the production process is modelled in the main function 'operational management' of the PIM. Operational management is subdivided into operational planning, implementation and operational control (COVP, 1986). Operational planning concerns the short-term decisions, in compliance with the actual daily results, that are focused on the implementation of the tactical plan. The tactical plan is a result from the tactical planning. Operational planning, therefore, concerns the day-to-day decisions. Implementation is the realisation of the operational planning. Operational planning and implementation are applied to processes within functions (Fig. 1, husbandry function, egg production function, etc.). Each function contains an operational control process that is concerned with the comparison of the operational plan and results achieved and with the harmonisation with other functions. Results of the short-term operational control are the input for the next cycle of operational planning, implementation and operational control (COVP, 1986).

4. Management tools

The daily cycle of operational planning, implementation and operational control is analyzed for the three critical success factors, control of feed consumption, ambient temperature and the early detection of diseases. Recommendations are given to develop adequate management tools.

4.1 Control of feed consumption

Two operational planning techniques for the determination of the daily feed consumption for a flock of hens can be distinguished. The first is based on calculating the planned feed consumption, and the second is based on *ad lib* feeding.

Feed consumption depends on the body weight, daily growth, egg production, ambient temperature, plumage condition, air velocity, genotype, activity, available area per hen, feed trough length and the shape, structure and concentration of the feed (IKC, 1994). Only a limited number of these variables are used for the actual planning of the feed consumption. The Dutch Extension Service (IKC,1994) gives formula's to calculate the daily feed consumption, which are based on the egg production (kg/day), growth per day, the body weight and ambient temperature. It is also possible to use standards that are delivered by the feed- or breeding company. Instead of calculating the planned feed it is read from the standard.

The second planning technique, which is most used in practice, is feeding the hens *ad libitum* till an age of 35 weeks and from then on restrict the hens in feed. The farmer looks for the optimum feeding strategy by reducing the amount of feed step by step. This is allowed as long as the egg production (egg number and egg mass), and the body weight remain at the same level or improve. This method is appropriate for hens older than 35 weeks, when there can be a certain amount of luxury consumption (Luiting, 1991). Finding the optimum feeding strategy for laying hens with this planning technique is more or less trial and error.

Implementation of the planned feed consumption in modern poultry houses is done by feed-computers. A feed-computer is a process computer that performs the daily distribution of the feed in the house (Postma,1994).

Operational control consists of the comparison of the actual feed consumption with the planned feed consumption. This can be done with planning method one when the feed consumption is really planned by using formula's or standards. If the planning method is 'trial and error', method 2, it is necessary to compare the actual egg production and body weight with their expected values. Differences between the expected and actual performances and changes in other functions, such as the number of hens in that flock, will be used to determine the corrective actions (more, the same or less food) for the next cycle of operational planning, implementation and operational control.

4.2 Control of the ambient temperature

The operational planning of the ambient temperature is kept very simple. The farmer sets the desired temperature somewhere between 20 and 25 °C and changes this only when outdoor climatic circumstances are extreme (very cold or warm). Sometimes he uses two set points, one for the light period and one for the dark period. The implementation is performed by very sophisticated computer based climate computers and the poultry farmer completely relies on the existing control technology that is incorporated in these climate computers (Postma, 1994). The poultry farmer checks at least once a day the realised ambient temperatures and compares them with the set points.

4.3 Detection of diseases

Operational planning for the critical success factor disease control differs form the palnning of the feed consumption and the planning of the ambient temperature. The incidence of diseaeses can not be planned. What can be planned are the actions to check for diseaeses and the implementation of a vaccination scheme. To prevent diseases a strict vaccination scheme should be followed, but this is a results of the tactical planning. Implementation consists of the actual vaccination and the collection of data for the disease control. Vaccination (preventive) or medication (curative) could be done by spraying, addition in food and water or by individual injections. Detection of diseases is based on data that are collected in the hen house. The farmer uses his senses (ears, nose and eyes) to observe the hens, the droppings and the litter in the house. These data are classified qualitatively, for instance: good or bad, and brown or red. Beside these qualitative data, the farmer uses quantitative information on the egg weight, egg numbers, egg quality (second grade eggs, floor eggs), feed consumption, water consumption, ambient temperature, body weight, uniformity and mortality (IKC, 1994) to detect diseases. An advantage of this type of data is that the data collection could be automated by using process computers and sensors (Belyavin, 1988; Postma, 1994; Lokhorst & Vos, 1994). Combinations of these quantitative and qualitative variables and the severity of deviations can be coupled to known diseases and aberrations in the production process, in order to detect these aberrations in time.

4.4 Recommendations

From the above analysis it could be concluded that at the moment the poultry farmer hardly pays attention to the operational planning of the three critical success factors. For the implementation the poultry farmer relies on sophisticated process computers. Operational control, however, asks a lot of attention of the poultry farmer. Management tools, therefore, in the first place should be aimed at supporting the operational control of the three critical success factors, control of feed consumption, ambient temperature and the early detection of diseases. Important daily quantitative variables for the operational control are egg production (egg numbers, egg weight, number of second grade eggs, number of floor eggs), feed consumption, water consumption, mortality, ambient temperature, body weight and flock-uniformity per group of hens or per compartment. Furthermore it is important to control qualitative data such as the colour of the faeces and the noise of the hens. The management tools must be able to deliver planned values (reference values) for these variables and to compare and combine them with the actual results of the group of hens. In this way the poultry farmer gets insight in the current state of the production process and he will be warned for possible aberrations in the production process concerning the three critical success factors feed consumption control, control of the ambient temperature and the early detection of diseases.

The development of such management tools and the research that is aimed at the determination of the quality of the information that is gathered in new housing systems, like the aviary system, is subject of research and will be worked out in other related articles.

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Chapter 3

An Automatic Egg Weighing and Counting System for Detailed Analysis and Control of Egg Production

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An Automatic Egg Weighing and Counting System for Detailed Analysis and Control of Egg Production

C. Lokhorst & H.W. Vos

Abstract

In poultry production the margin between egg prices and production costs is small. Adequate and timely information of the production process enables the poultry farmer to make correct decisions. To get insight into the variation of egg production in a house an Egg Weighing and Counting System (EWACS) has been developed. The system counts and weighs the eggs per individual or per group of laying nests. This information can be used to signal timely deviations in the production process. The prototype of the system and the results from laboratory tests are described.

Test results show that damage to the egg shells, caused by the EWACS, occurs when there are eight eggs or more per laying nest. With good tuning of the EWACS it is possible to have less than 2% faults in counting the eggs. The faults in weighing are less than 4%. The percentage of second grade eggs, faults in counting and faults in weighing increase when the number of eggs per laying nest increase from four to 12. The total percentage of second grade eggs and the faults in weighing decrease for 15 eggs per laying nest as compared with 12. The conclusion is that the EWACS can be used in battery housing systems as well as in aviary housing systems and that it will give a detailed view of egg production in the house.

1. Introduction

Stable egg prices, increasing production costs and an increase in larger farms are the features of poultry production in the Netherlands over the last decade.[1, 2] The margin between egg prices and production costs is very small and so a small change in production costs can greatly effect the farmer's income. The cost of the product[3] is mainly attributable to feed costs (60%), costs of young hens (16%) and fixed costs (20%).

The variable costs such as feed costs and costs for health care can be influenced by the poultry farmer during the production process. This means that daily decisions influence the final economic results of the flock. Decisions are dependent on timely and reliable data about the flock and so information itself becomes an important production factor.[4, 5] .

Traditionally, data collection for laying hens is performed per house or flock. The farmer calculates the average production results per week or per 4-week period per flock.[6] Occasionally, eggs are counted per compartment that is a part of the house. Within a compartment the eggs can also be counted per row or floor as shown in *Fig. 1*. The average egg weight is based on weighed containers and is usually done per house or compartment.

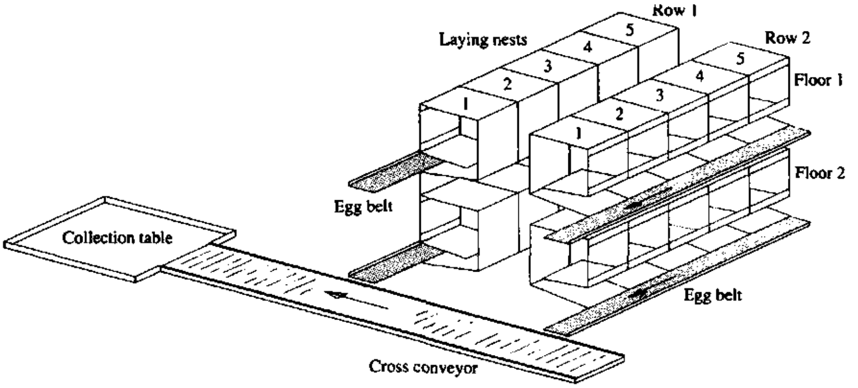

Fig.1. Principle of egg collection in a poultry house

Counting and weighing eggs per laying nest would enable a detailed insight to be obtained into causes of variation of egg production in the house. It will be possible to compare groups of animals within an individual house and consider the effect of different production factors such as diseases, climate, light, feed or water. To do this the data must be stored in a management information system.

The use of the data depends on the housing system. In aviary systems the data can be used for the selective opening and closing of laying nests.[7] For aviary and battery housing systems the number of eggs and the average egg weight can be used to signal changes in the production process. Egg weight provides a quicker indication of deviations than the number of eggs.[8] Production differences between different locations in the house can be detected if data are collected per laying nest or groups of laying nests. This paper describes the development and the laboratory test of an Egg Weighing And Counting System (EWACS) for recording the egg production per laying nest or per group of hens in an aviary system.[7] The principles of the EWACS can also be used in battery housing systems.

2. Development of the EWACS system

2.1. Egg collection

In large-scale poultry farming, collecting is partially or fully automated. *Fig. 1* shows the general principle of egg collection. The eggs roll on to an egg belt in front of or behind the cages or laying nests. The belts take the eggs to the front of the house. Two systems can be used for the transition of the eggs to the cross conveyor. With system 1 the cross conveyor is fixed and the eggs are transported by using an elevator. All egg belts can run simultaneously. In the second system the cross conveyor is moved from floor to floor. Only one egg belt runs per row at any one time and the eggs roll directly on to the cross conveyor. At the end of the cross conveyor the eggs are collected semi-automatically (manually) or automatically. Newly installed egg collection systems nowadays are only of the second type.

2.2. The EWACS system

Each laying nest in a compartment has a unique code consisting of an eight-digit number. The meaning of this code, from right to left, is as follows: three digits are used for the nest position in the row, two digits for the row position in the compartment, one digit for the floor position in the row, and two digits for the compartment or house number.

The freshly laid eggs roll from the laying nest on to the egg belt. The belt runs once or twice daily. The eggs arrive at the end of the belt. *Fig. 2* shows the end of the egg belt, where the EWACS is positioned. The position of the laying nest is marked by ridges (B) on the belt. The ridges prevent eggs from rolling to a position on the egg belt that corresponds with any other adjoining laying nest. The ridges have a height of 6 mm, so the belt may have a slope up to 12° before the eggs roll over the ridge. A slope of this magnitude will in practice not occur. Small slopes occur only at the transition of two laying nest blocks.

Laying nests are counted by the magnetic approach switch A1, and the start position of the egg belt is determined by the magnetic approach switch A2. These two switches are placed just one laying nest length from the end of the belt. To ensure a smooth transition of eggs to the egg separator (G) a small cylinder (H) is placed at the end of the egg belt. The eggs are separated into three parallel rows. The egg separator transports the eggs to the carousel which consists of six parallel trays (F). The trays guide the eggs to the end of the frame (D). The frame is moved upwards and downwards by the camshaft (I). When the frame is down the egg lies on the balance (C). When the frame comes up, the egg is pushed by the next tray to the egg collecting table (J). Here the farmer collects the eggs. The upward and downward movement of the frame decreases the force on the rolling egg and causes a complete stop on the balance to read the voltage of the balance. The magnetic approach switch (E) delivers the interrupt signal to weigh the egg.

When all the eggs are counted and weighed the belt should return to its starting position. In this position the ridges are positioned between the laying nests. To optimize the use of the belt, the ridge pattern is duplicated on the part of the egg belt that lies underneath the operational part.

Counting and weighing of eggs are combined. The egg separator (G) ensures that the eggs come one after another. When three eggs arrive simultaneously they are separated into three rows. To handle this, each weighing unit (K) consists of three balances (C) next to each other. In this way each egg is weighed individually. If the weighing signal exceeds a given limit, e.g. 30 g, then it is assumed that an egg is weighed and the egg is counted. The weighing principle is based on a strain gauge with internal temperature correction and signal suppression. Signal suppression is used to filter the signal that comes from the strain gauge. Temperature influences the signal from the strain gauge, so to improve the quality of the measurement signal suppression and temperature correction are used.

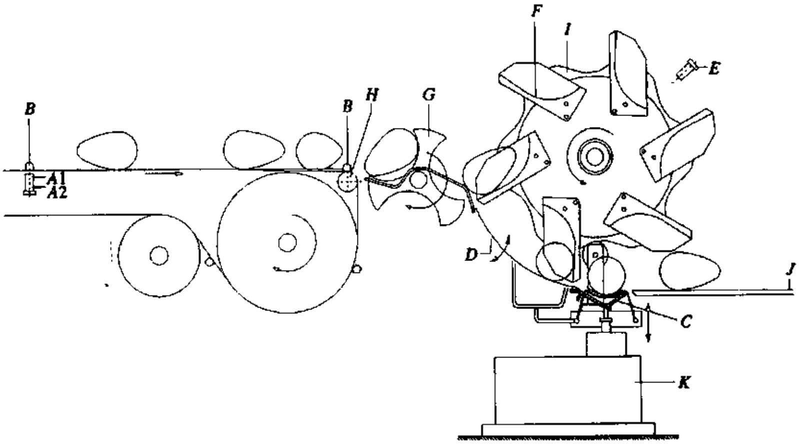

Fig.2. Egg flow through the EWACS. A1, nest counter sensor; A2, start position sensor; B, ridge for nest separation; C, balance; D, frame; E, sensor for weighing signal; F, carousel with six trays; G, egg separator; H, small cylinder; I, camshaft; J, egg collection table; K, weighing unit

Dirt on the weighing platform cannot disturb the weighing results because when no egg is detected, the weighing signal is automatically corrected and set to zero. The EWACS is constructed in such a way that it can function in a normal house where dust, air gases and moisture are present. The materials chosen are free of maintenance. The safety of the hens and of the poultry farmer is guaranteed by shielding any rotating parts. Underneath the egg separator and the carousel, a small tray is placed to catch dirt, including feathers. This should be cleaned regularly.

The counting and weighing unit is supported by a framework which can be moved up and down from floor to floor. A magnetic approach switch detects whether the egg separator is in front of an egg belt. The EWACS works only when it is exactly in the right position, otherwise eggs would be damaged. This should be checked regularly to ensure that it is operating correctly.

Signals from the magnetic approach switches and the weighing platforms are processed and linked by using a μMAC-1060 from Analog Devices Inc. The μMAC-1060 is an industrial modular I/O processor. It consists of an 8 MHz 80C188 CMOS microprocessor, a 128 kbyte battery backup RAM memory, a 128 kbyte EPROM memory, one serial communication port and one data acquisition unit.

2.3. *Operating the EWACS*

The EWACS has two possibilities of collecting eggs. In the automatic position (option 1) the EWACS collects and stores data per laying nest. Individual parts of the EWACS, such as the carousel, the egg separator and the egg belt are started in a particular order. In the manual position (option 2) the poultry farmer starts the egg belt. In this position no data are stored. The manual position is added to ensure the possibility of egg collecting when the weighing unit is not required to work.

Fig. 3 shows the control panel (X) that is situated near the egg collecting table. This panel contains switches to control the speed of the egg belt and the carousel as well as switches for manual control, in case of a breakdown. Beside this panel an emergency button (Y) and a normal start and hold switch (Z) are installed. The latter switch should be used when everything is operating well.

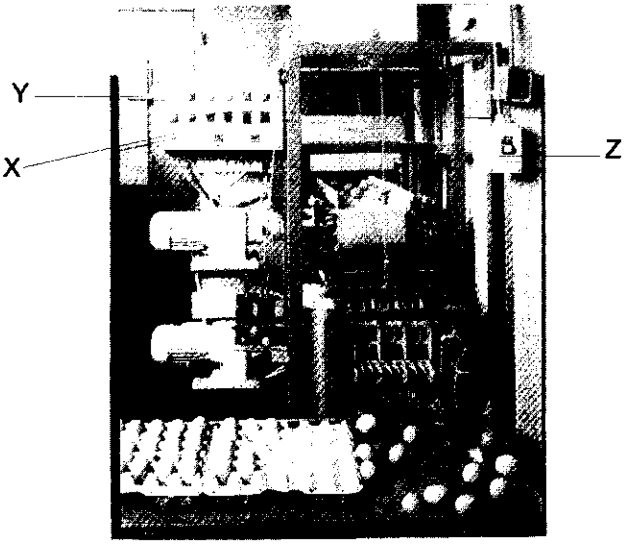

Fig.3. Control panel of the EWACS. X, control panel; Y, emergency button; Z, hold switch.

Normally, the EWACS is used in the automatic position. The poultry farmer controls the egg collection by using the start/hold switch. When an egg belt is finished and the EWACS is stopped, the system moves to the next floor. When all the floors have been completed, all data are stored in the, μMac 1060.

The μMac 1060 is connected to a personal computer. Once per day the data from the μMac 1060 are read into the management information system and the data are deleted from the μMac 1060. Analysis of data takes place in a management information system.

The balances must be calibrated and this is done by placing small weights on the balances. A program on the personal computer is used to calibrate the balances periodically.

3. Experiments

3. 1. Materials and methods

3.1.1. *General*

A prototype has been built and tested under laboratory conditions. Small-scale experiments without hens were carried out, using EWACS in combination with one block of five individual laying nests. The egg belt speed was set to 1.23 m/min. The speed of the carousel is varied between 52 trays per min and 60 trays per min. If eggs role over to the next laying nest, data from these two laying nests are influenced. To prevent this and to measure different laying nests independently, eggs were placed in laying nest numbers 1, 3 and 5.

To test the EWACS, four different densities of eggs per laying nest were used, namely, 4, 8, 12 and 15 eggs per laying nest. This range will be appropriate for using the EWACS in a Tiered Wire Floor (TWF) system[7, 9] and in a battery system. Fifteen eggs per laying nest is extreme, but 12 eggs per individual laying nest can be expected in a TWF system. This expectation is based on the average number of hens per laying nest, the maximum egg production and the distribution of the hens over the laying nests.

3.1.2. *Egg shell quality test*

The first experiment served to examine the EWACS for the careful handling of eggs in relation to the egg density per laying nest. Egg quality was measured by the percentage of second-grade eggs.[10, 11] Classified deviations were none, hair-cracked, cracked and broken,[11] in increasing order of shell damage. Eggs from White Leghorns were judged on egg shell deviations with a candling lamp before the eggs were laid manually in the laying nest and after they were counted and weighed by the EWACS. The four egg densities per laying nest were repeated twice with a speed of the carousel of 52 trays per min and twice with a speed of 60 trays per min.

For the analysis of the data, ordinal logistic regression was used, assuming an underlying logistic distribution for the severeness of damage and multinomial distribution for the numbers in the different classes. Effects are defined as shifts in this distribution. For an explanation of the model and its analysis, see McCullagh and Nelder.[12] All the eggs were judged before they were laid in the laying nests, so the distribution over the three classes hair-cracked, cracked and broken was known. This study examined the change in the incidence of hair-cracked, cracked and broken eggs, owing to handling of the eggs by the EWACS. The shift in the distribution before and after handling the eggs was tested using *t*-tests based on the estimates of effects and their approximate standard errors. Explanatory variables included additive effects of repetitions (1-4), laying nest number (1, 3 or 5), speed of the carousel (52 or 60 trays/min) and a linear effect for the number of eggs per laying nest (4, 8, 12 or 15).

3.1.3. Accuracy test

To test the correctness of counting and weighing, a second experiment was carried out. The same laying nests and egg densities per laying nest were used as in the egg shell quality experiment. Results from the egg shell quality test were also used for the accuracy test. In addition, five more repetitions were carried out with a speed of the carousel of 60 trays per min, so in this test, nine repetitions were made. Between repetition four and five, the EWACS was tuned again. The position of the egg separator compared to the egg belt and the carousel was slightly changed. Each time the eggs were collected, the EWACS stored the number of counted eggs and the average egg weight per laying nest. The eggs were counted and weighed manually before the test started.

3.1.3.1. Faults in counting. Ordinal logistic regression with two classes was used to analyse the number of faults in the counting of eggs. The variables were the number of eggs per laying nest (4, 8, 12 and 15), the laying nest number (1, 3 or 5), the speed of the carousel (52 or 60 trays/min) and the tuning of the EWACS between repetition four and five.

3.1.3.2. Faults in weighing. The weights of the eggs were measured by hand and by the EWACS and averaged per laying nest. The difference between these two averages is called the deviation in egg weight per laying nest and this is a continuous variable. The accuracy of the weight registration can be judged by the mean of the deviations and the variation of the deviations. Both mean and variation are simultaneously modelled, as described by Carroll and Ruppert[13] The same explanatory variables as mentioned in the test for the accuracy of the counting of the eggs are used. For a more elaborate description of the statistical methods used, see Keen.[14]

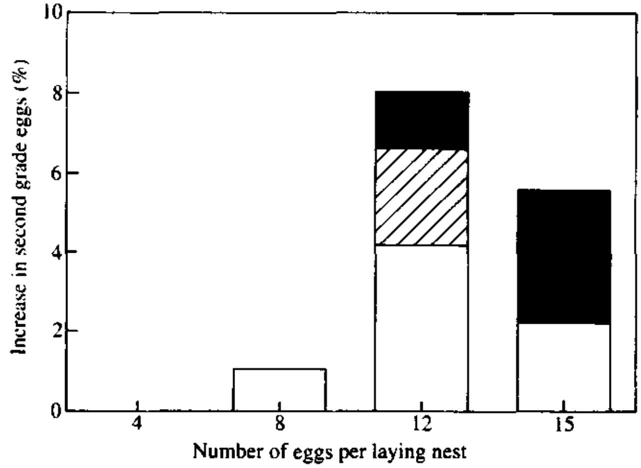

Fig.4. Damage to the egg shell caused by the EWACS in relation to the number of eggs per laying nest. ☐, hair-cracked; // cracked; ■, broken

3.2. Results

3.2.1. Egg shell quality

Fig. 4 shows the effect of the number of eggs per laying nest on egg shell quality. The increase in second grade eggs caused by the EWACS is given. In the group with four eggs per laying nest, egg shell quality was unaffected. In the group with eight eggs per laying nest there was only a slight increase in hair-cracked eggs. When there were more eggs per laying nest, 12 or 15, there was also an increase in cracked and broken eggs. The total percentage of damaged eggs decreased with an increase from 12 to 15 eggs per laying nest. In the group of 15 eggs no cracked eggs were found, but the percentage of broken eggs was greater than for 12 eggs per laying nest. So, when there are more eggs per laying nest there is more damage, and the severeness of the damage also increases, which is also confirmed by the statistical analysis.[14]

3.2.2. *Accuracy test*

Results from the accuracy test show that in repetitions five to nine, after the tuning of the EWACS, only one out of the 60 measurements showed a fault in the counting of the eggs, which amounts to 1.7%. In repetitions one to four, six out of the 45 measurements showed a fault in the counting, which is 13.3%. It shows that the number of faults in counting can be reduced with a proper tuning of the EWACS.

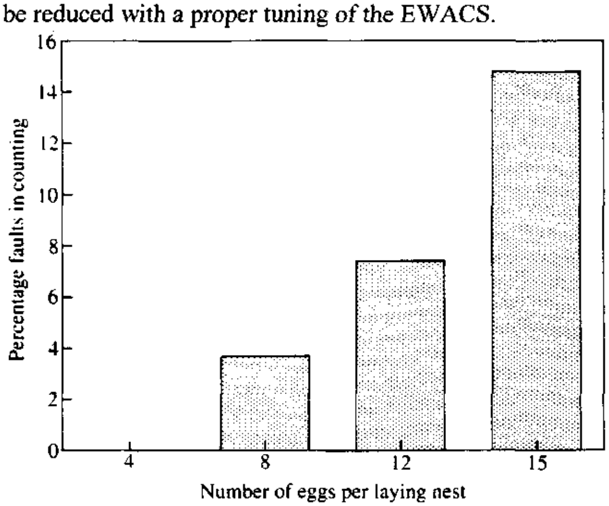

Fig. 5. Relationship between the number of eggs per laying nest and the percentage of faults in counting the eggs

Fig. 5 shows the relationship between the percentage of faults in counting and the number of eggs per laying nest. In the group with four eggs per laying nest no faults in counting occurred. The faults in counting increased from almost 4% with eight eggs per laying nest to more than 14% with 15 eggs per laying nest. Using a one-sided *t*-test the effect of the number of eggs per laying nest on the percentage of faults in counting the eggs is significant ($P \leq 0.05$). Both speed of the carousel and tuning of the EWACS have a possible relationship with the percentage of faults in counting, but this is not significant. It is difficult to separate those two effects because they are correlated, but it seems that the effect of the speed of the carousel is more important than the effect of the tuning. There is a negative relationship between the speed of the carousel and the number of eggs per laying nest.

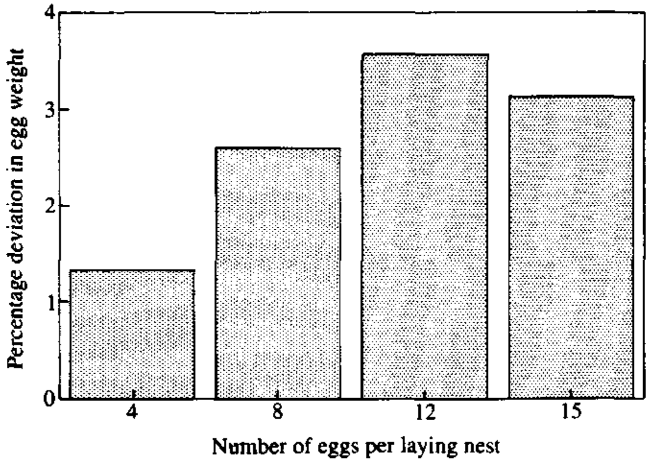

Fig. 6. Relationship between number of eggs per laying nest and percentage deviation of the egg weight

Fig. 6 shows the results for the percentage deviation in the average egg weight per laying nest with different numbers of eggs per laying nest. The percentage of deviation of the average egg weight is the difference between the egg weight measured by the EWACS and the egg weight measured by hand divided by the egg weight measured by hand. The fault in weighing the eggs is 1.3% in the group with four eggs per laying nest. The fault in weighing increases to 3.5 when 12 eggs per laying nest are used. With 15 eggs per laying nest the fault in egg weighing is slightly lower than when 12 eggs were placed in the laying nest. The results of the fitted models show that the number of eggs per laying nest influence the mean of the deviations in egg weight as well as the variation.

4. Discussion

The influence of the number of eggs on the egg shell quality is caused by the increase in contacts between the eggs. Each time an egg contacts another egg or a part of the collection system there is a certain risk of damage. When there are more eggs per unit area of egg belt, the risk of damage increases. *Fig. 5* shows that the total damage with 15 eggs is lower than with 12 eggs. It can be seen that with 12 eggs per laying nest there are more hair-cracked and cracked eggs than with 15 eggs. An explanation can be that the eggs have much contact during transport to the EWACS. With a density of 15 eggs per laying nest the eggs have very little room to roll, so the chances of hair-cracks and cracks will be lower. The incidence of broken eggs increased, when the eggs per nest increased from 12 to 15. This happens in the EWACS itself. EWACS has difficulties with this number of eggs. The speed of the carousel is probably too low to ensure that all the eggs are removed from the egg belt quickly enough.

In comparison with a normal egg collecting system EWACS has more transitions for the eggs. Normally there is only the transition from the egg belt to the cross conveyor. With the EWACS there are transitions from the egg belt to the egg separator, from the egg separator to the carousel, from the carousel to the balance and from the balance to the egg collection table. Each extra transition causes an extra risk of damaging the eggs. For a smooth flow of the eggs through the EWACS it is therefore important that all the transitions are tuned properly. This could also be seen in the results of the counting. Before tuning, the results were worse than after the tuning of the EWACS.

The influence of the number of eggs per laying nest on the faults in weighing and counting is more difficult to explain. When there are more eggs per laying nest, there is a greater chance of three eggs being on the balances simultaneously. An explanation may be that simultaneous weighing causes the deviation. Because there are three balances next to each other, there is a maximum of three eggs that should be measured at a certain moment. Because of small vibrations in the system, the weighing signals can be influenced.

Results show a possible negative relationship between the speed of the carousel and the faults in the counting. With a higher speed of the carousel the eggs are removed more quickly from the egg belt, so the contact between the egg belt and the carousel is less. As mentioned earlier, the pattern of small vibrations in the system may be different when another speed of the carousel is used. When the carousel runs faster there is less time for weighing the egg. Weighing is done by using an interrupt signal from a magnetic approach switch. The signal of the weighing platform at that moment is used. When the carousel runs faster, this signal comes faster too. So there is a difference in the moment of measuring after the egg arrives on the weighing platform. This may partly explain the influence of the speed of the carousel on the faults in counting.

There appears to be an increase in faults in counting and weighing when there are more eggs in one laying nest. If this becomes too much of a problem, eggs should be collected more frequently. Another possibility is the use of laying nests, controlled by selective opening and closing systems. This can also be useful to achieve a proper distribution of hens over the whole house.

The software can be adjusted so that only eggs in a certain weight range are used to calculate the average weight per laying nest. In the present version, only the lower limit of 30 g is used. When an upper limit of e.g. 100 g is also used the average weight per laying nest can be determined more accurately. An egg weight of more than 100 g hardly ever occurs. Weights below the lower limit are not considered. Weights above the upper limit are counted but not used to calculate the average weight. Weights between the lower and upper limit are used to count and to calculate the average weight.

5. Conclusions

In battery housing systems the expected maximum number of eggs per cage is four or five eggs, depending on the number of hens per cage. The test results show that with these densities there will be no increase in second grade eggs caused by the EWACS and that the faults in the counting of the eggs are negligible. The deviation in the weighing will be less than 1.5%.

When EWACS is used in a Tiered Wire Floor system, [9] and the hens distribute the eggs equally over the laying nests, the expected average number of eggs per laying nest will be eight eggs. The increase of second grade eggs caused by the EWACS will then be about 1%. With good tuning of the EWACS, the faults in counting can be lower than 2%. The deviation of the egg weight per laying nest will be less than 3%.

In the TWF system, hens have the freedom to choose a laying nest. If the hens prefer some laying nests, the number of eggs per laying nest can be larger than the average of eight eggs. When 12 eggs are laid in one laying nest the increase in second grade eggs caused by the EWACS will be higher than 6%. The faults in the counting increases to 7% and the deviation in egg weighing increases to more than 3%. It is important, therefore, to keep the number of eggs per laying nest as low as possible. A solution is to collect the eggs twice a day. By using the EWACS one can see how the eggs are distributed over the laying nests and if it is necessary to collect the eggs more than once a day.

The EWACS prototype makes it possible to count and weigh eggs that are laid in each laying nest. The aim of the project is to get detailed and reliable data from small groups of birds. The EWACS delivers these data and so it can be useful in further research on the development of housing systems and other research.

Another prerequisite is that data should be delivered in time. The EWACS delivers the data right after the egg collection process in the management system. It is also possible to see differences in the laying pattern over a day if the eggs are collected more often.

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Chapter 4

Examination of egg number and egg weight variables and their effects on daily management in aviary systems for laying hens

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Examination of egg number and egg weight variables and their effects on daily management in aviary systems for laying hens

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Abstract

1. Characteristics of egg numbers and mean egg weight were examined for their usefulness in the daily management of aviary systems for laying hens.

2. A number of 3238 brown Isabrown/Warren hens were housed in 1 compartment, a separated part of the house where the hens could move around freely, of a Tiered-Wired-Floor aviary system (TWF-system). An automatic Egg Weighing And Counting System (EWACS) was used to count and weigh eggs daily from 2 tiers of laying nests on 1 side of the compartment and the number of eggs for the whole compartment were counted daily by the farmer. Each tier was divided into 16 blocks of 5 individual laying nests. Two adjoining blocks were called a group. To prevent hens from walking along all the laying nests in a tier, partitions were placed on the perches in front of the laying nests, between nest groups 2-3, 4-5, and 6-7.

3. After the first 3 weeks of the laying period, the distribution of egg numbers over the nest groups within a tier became stable. If egg numbers were counted daily from only 1 nest group the coefficient of variation was 23.1 %. If the eggs from the whole compartment were counted daily, the coefficient of variation for the number of eggs was 2.8 %. The nest group, presence of a partition and tier level influenced the daily number of eggs.

4. The distribution of the mean egg weight over the different nest groups within a tier was stable for the whole laying period. The coefficient of variation of the daily mean egg weight for a nest group was 3.1 %. The difference in mean egg weight between nest groups was small, between 0.1 and 0.6 g, and the level of tiers and the presence of partitions between nest groups had no effect on the mean egg weight.

5. It could be concluded that egg numbers could not be estimated reliably by taking samples from a group of laying nests or a tier, but that it was necessary to count all the eggs from a compartment. The daily mean egg weight, however, could be estimated reliably on the basis of a sample of eggs from a nest group or a tier. By using EWACS frequent samples could be taken, which diminished the coefficient of variation so that the reliability of the data increased.

1. Introduction

Reliable data are required for effective daily management of an aviary housing system for laying hens. According to Lokhorst *et al.* (1995) the 3 critical success factors for production management in aviary systems are the control of the ambient temperature, the food control and the prevention and early detection of diseases. The number of eggs and the egg weight can be influenced by the ambient temperature (Kampen, 1984; Marsden & Morris, 1987) and they are important variables in controlling feed supply. Feed can be restricted gradually as long as the mean egg weight, the number of eggs and the mean body weight are stable and do not decrease. Changes in egg numbers and mean egg weight can be used for monitoring the occurrence of diseases and aberrations, such as respiratory disorders, osteomalacia, digestive disorders, strong feed and water restriction, extreme hot day, change in feed composition and parasites (Lokhorst, 1995).

If egg numbers and egg weight are to be used as variables for production management in aviary systems, the method of measuring these variables becomes important. Because aviary systems are new housing systems (Blokhuis & Metz, 1992), it is important to investigate the characteristics of the data to be used for the daily management. It should be clear how the data must be gathered; is it, for instance, sufficient to take a sample from a group of laying nests or a tier or must data be gathered from the whole flock ? What is, for instance, the range of the normal variation in egg numbers and egg weight in aviary systems ? Aberrations in production data only can be detected if deviations in the measured data are larger than the normal variation.

In aviary systems, hens are free to choose their own laying nest. If the distribution of eggs over the laying nests is constant, it is not necessary to count the eggs from all the laying nests in order to monitor the daily variation in the production. Rietveld-Piepers (1987) and Appleby *et al.* (1988) reported that eggs in deep-litter systems were not equally distributed over the laying nests. More eggs were laid in the upper tiers, and hens also preferred corner nests. Social dominance of hens can influence the total number of eggs per laying nest. Cunningham *et al.* (1987,1988) described how egg production of high-ranking hens in high-density cage environments was higher than that of low-ranking birds. If high-ranking hens in aviary systems produce more eggs and they take over the most preferred corner nests, this may partly explain extra production in the corner nests. Another explanation can be that hens or eggs in a laying nest attract other hens to lay an egg in that particular laying nest. Rietveld-Piepers (1987) concluded that there is a positive relationship between the dominance order and the time of first oviposition. Hens do not enter the nest before the first oviposition, thus dominant hens have the first choice of nests.

There is little information available about the distribution of mean egg weight over the laying nests. Cunningham *et al.* (1987) stated that there is no relationship between the order of dominance among hens and egg weight. Douglas *et al.* (1986) and Lee & Choi (1985) found that eggs laid early in the morning are heavier than those laid later in the day. If hens choose their favourite nests in the morning, it is possible that the mean egg weight in those nests will be higher than in the less favoured nests. Therefore, it may be assumed that there will be some difference in the egg numbers and the mean egg weight found in each laying nest. The hypotheses tested in this study were that there was a uniform distribution of eggs over the laying nests and that time (age of the hens) had no influence on this distribution from 4 weeks after the start of the laying period. After 4 weeks all hens are in lay and they should be accustomed to the laying nests. The same hypothesis was used for the mean weight of the eggs collected from the laying nests.

This study aimed to clarify the statistical value of egg numbers and egg weight as variables to be used for daily management in aviary systems. This study concerns the spatial and temporal distribution of egg numbers and mean egg weight within an aviary system, especially how these variables vary from day to day within tiers and groups of laying nests. The result is a description of the conditions for good sampling techniques for egg numbers and mean egg weight in an aviary system, in order to provide reliable information for the management decisions on issues like food control, temperature control and disease control.

2. Materials and methods

2.1 Animals and housing system

Sixteen-week-old Isabrown/Warren (a commercial strain) hens were housed in a Tiered Wire Floor system (TWF-system) (Ehlhardt *et al.*, 1988). The house was divided into 2 compartments of 7 m wide and 23 m long (Figure 1). A compartment was a section of the house where hens could move around freely. Each compartment housed 3238 hens. The bird density was 20.1 hens per m^2 floor space, 40.5 hens per round feeder and 8.8 hens per individual laying nest. Water was provided by drinking nipples, 10 birds per nipple. During the laying period, the hens had 14h of light and 10h of darkness. The hens were fed *ad libitum* with a commercial layers' diet. Two rows of wooden, individual laying nests (25 cm wide) were placed in each compartment (Figure 1). The row of laying nests in the middle of the house had 3 tiers and the row on the side wall had 2 tiers. Litter was continuously available on the ground. Perches were mounted over the top tier.

2.2 Data recording

During a period of 9 months, starting from the begin of the laying period, the farmer collected and counted the eggs daily from the whole compartment.

An automatic Egg Weighing And Counting System (EWACS) (Lokhorst and Vos, 1994) was installed to record automatically the egg production (egg numbers and egg weight) from groups of laying nests within 2 tiers on the side wall of compartment 2 (Figure 1).

Five adjoining laying nests were chosen as the unit for measurement of the egg production, and this was called a block. Each tier was divided into 16 blocks of laying nests. Two adjoining blocks formed a nest group. Partitions were placed on the perches in front of the laying nests between nest groups 2-3, 4-5 and 6-7, to prevent hens from walking along all the laying nests. The front wall of the compartment, close to nest group 1, and the end wall of the compartment near nest group 8, functioned as partitions. Thus, each nest group consisted of a block that was adjacent to and a block that was not adjacent to a partition. The 2 tiers together formed the EWACS-row. Data from the row of tiers with laying nests in the middle of the house (Figure 1) were not measured with an EWACS.

The EWACS was used twice a day to collect the eggs. Data were aggregated to number of eggs and egg weight per block per day. Complete EWACS data sets for all nest groups and tiers were obtained for 153 d.

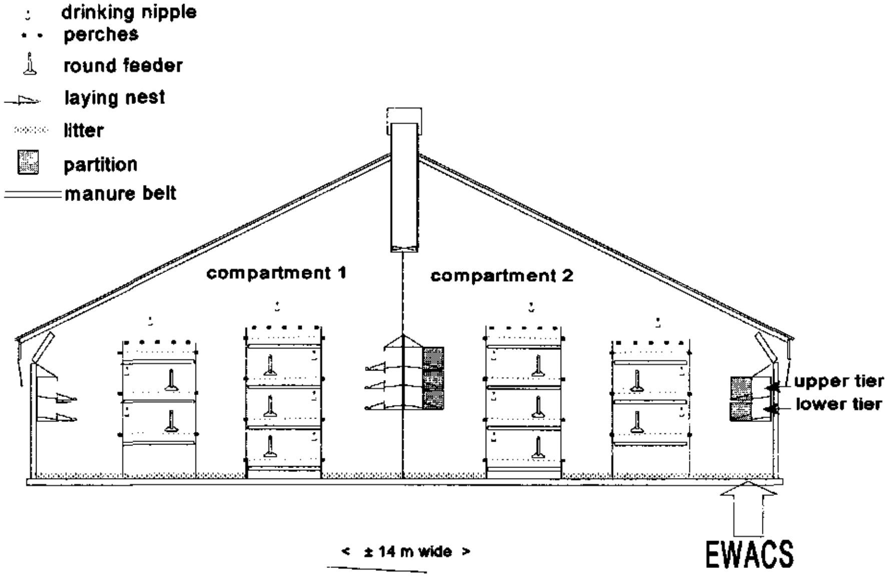

Figure 1. Schematic outline of the Tiered Wire Floor system (TWF) with 2 compartments and the place of the EWACS.

2.3 Statistical analysis

The statistical analysis was based on generalised linear mixed models (GLMM) (Engel and Keen, 1994). A GLMM model was used because this made it possible to model simultaneously the main effects of age, nest groups, tiers and partitions and the daily variation in nest groups, partitions and tiers on the number of eggs and the mean egg weight. GLMM can be seen as a logistic analysis of variance, characterised by a link function $g(\mu)$, by separate linear models for fixed and random effects and by a distribution (in combination with the variance function) of the response variate (Engel and Keen, 1994). In formula this is:

$$
\begin{aligned}
y &= \mu + \epsilon \\
g(\mu) &= \textit{fixed effects} + \textit{random effects} \\
var(\epsilon) &= \phi \, \mu^{\alpha}
\end{aligned}
$$

The choice of fixed effects, random effects and α will be discussed for each of the response variables below. The variance of ϵ is supposed to be related to the mean according to a power relationship. The dispersion factor ϕ is a constant to be estimated from the data.

The natural logarithm was chosen as link function, because, at the logarithmic scale, relative effects were considered instead of absolute effects and egg numbers and mean egg weight always were greater than 0. A constant standard deviation at the logarithmic scale implies a constant coefficient of variation at the original scale.

The model for the fixed effects was:

```
fixed effects = t + ln(t) + PE * G * P * T
```

where:

t: number of days in the experiment,

PE: period, with levels 1 to 4 representing the first 4 weeks in the experiment, respectively, and level 5 represents the remaining period,

G: nest group number, with levels 1 to 8, representing the positions of the nests,

P: partition, with level 0 (adjacent) or level 1 (not adjacent) to a partition

T: tier, with level 0 for the upper tier and level 1 for the lower tier of laying nests.

An asterisk in this formula indicates the main effects plus the corresponding two-way and three-way interactions. Two factors were relevant in modelling the effects of age. The mean change with age of the egg weight and the number of eggs has been described with the incomplete gamma function *t + ln(t)*. The mean egg weight normally gradually increases with age and the hen-day egg production, and thus the number of eggs, increases until the maximum production is reached and from there on there is an almost linear decrease in the hen-day egg production (Adams & Bell, 1980). Both types of curves can be modelled with an incomplete gamma function and a further advantage of the incomplete gamma function is that it is linear at the logarithmic scale. An initial instability, induced by G, P and/or T, in the distribution of the egg numbers and egg weight over the laying nests was modelled with the variable PE. The random effects were related to variations between days and were described with the model:

```
random effects = D / (G * P * T)
```

where:

D:day, represents the, average (random) differences between days.

The slash in this formula indicates a main effect of D and the interaction terms of G, P and T with D. Thus, the daily variations in effects of G, P and T are modelled.

The variance function for the egg numbers is based on a Poisson distribution ($\alpha=1$), which would be the correct distribution if eggs were laid randomly in the laying nests. A Gamma distribution ($\alpha=2$) with a constant coefficient of variation is assumed for the mean egg weight.

The analysis method is an analogue of the iteratively reweighted least squares algorithm for generalized linear models, with residual maximum likelihood replacing least squares to account for the variance components. Estimates for random effects are included in the weights (Schall, 1991). For an extensive description of the fitting method, see Engel and Keen (1994). Calculations were performed with the GENSTAT statistical program (Genstat 5 Committee,1993), using the procedure IRREML, which is part of the GLW-library.

To judge the statistical significance of variance components as well as of fixed effects their estimates are compared with their standard errors. The t-test was used to indicate the order of magnitude of the significance. For fixed effects this will be a good approximation, for variance components this is reasonable only for large t-values.

3. Results

3.1 General

To show the pattern of egg weight and the number of eggs and to show a preview of the daily variation in both variables, Figure 2 is given as an example of the data of block 14 in the upper tier. Egg weight and the number of eggs gradually increased during the laying period. The number of eggs reached a peak, that was followed by a decrease in egg numbers.

3.2 Daily variation in egg numbers

When hens displayed no preference for specific laying nests and eggs were laid in the laying nests at random, the dispersion factor (ϕ) for the Poisson distribution would be 1. The dispersion factor for the daily egg numbers per block was 0.81 (se = 0.02), a value lower than expected for a Poisson distributed variable. This indicated a positive correlation between blocks within days. The number of eggs in a particular block on a particular day was influenced by the number of eggs in adjacent blocks on that same day. The presence of hens or eggs in laying nests stimulated other hens to lay their eggs in the neighbourhood.

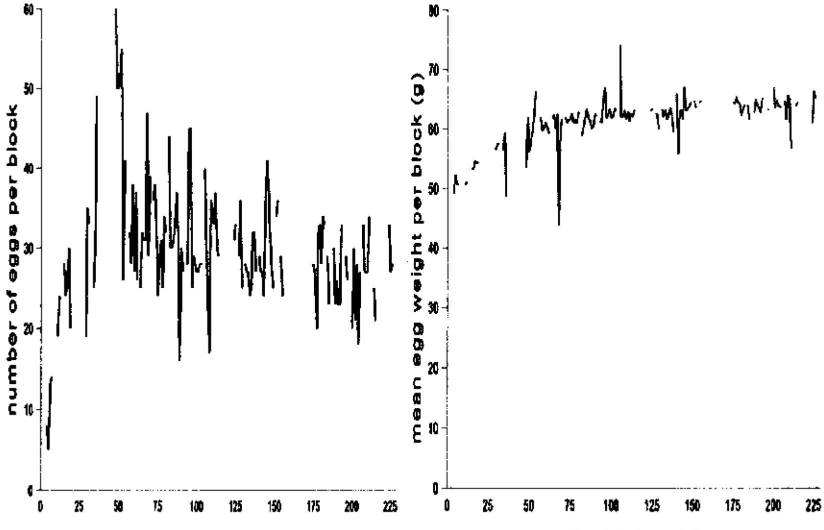

Figure 2. EWACS measured egg numbers and mean egg weight per d in block 14 of the upper tier.

The number of eggs per block varied significantly (P < 0.001) from day to day. The random daily variation (σ^2_D) was estimated as 0.0083 (se = 0.0020). Significant ($P < 0.001$) interactions were found between days and nest groups ($\sigma^2_{D.G} = 0.0018$; se = 0.0005) and between days and tiers ($\sigma^2_{D.T} = 0.0091$; se = 0.0015). Other interactions were not significant.

The components (σ^2_D, $\sigma^2_{D.G}$, $\sigma^2_{D.T,}$ ϕ) that described the variation in the number of eggs data, could be used to determine the coefficient of variation for a nest group by using the

formula: $CV_{nest\ group} = \sqrt{\sigma^2_D + \sigma^2_{D.G} + \sigma^2_{D.T} + \frac{\Phi}{\mu}}$

These components could be used as well to determine the total daily variation for a tier or the whole EWACS-row, taking into account the averaging over the random variation effects. Figure 3 shows the coefficients of variation for a nest group, the row (all the nest groups that were measured by the EWACS), and the whole compartment. Data for the whole compartment were also used to calculate moving averages (MA) with time lags of 3, 5 and 7 d.

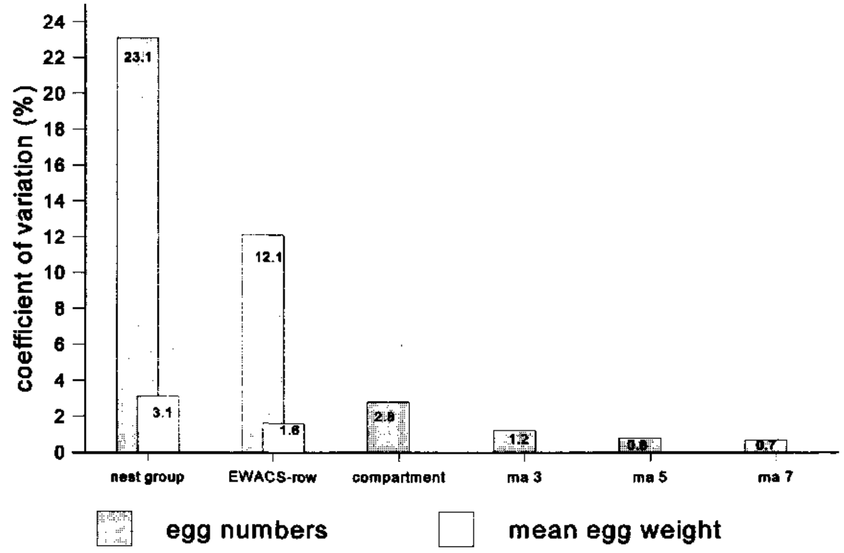

Figure 3. Coefficients of variation, based on EWACS data, for daily egg numbers and mean egg weight for a nest group and the EWACS-row. Coefficients of variation for the number of eggs, also are given for the total compartment and for moving averages (MA) with time lags of 3, 5 and 7 d, of these compartment data.

The coefficient of variation for the number of eggs in a nest group was 23.1 %. Therefore, if egg number data from one nest group are collected, a daily variation up to

23.1 % will be normal. Then abnormal situations only could be detected if the number of eggs of successive days vary more than 23.1 %. If egg number data were based on the total number of eggs of the whole compartment, the coefficient of variation was 2.8 %. This coefficient of variation could be reduced further by averaging these data over days. The coefficient of variation for compartment data that were averaged over 7 d became 0.7 %.

Table 1. Daily egg numbers and mean egg weight per nest group, and tier, and for blocks with and without presence of a partition.

	Egg numbers		Mean egg weight	
	(ln-scale)	eggs/block	(ln-scale)	g
Nest group (G)	sed = 0.022		sed = 0.0030	
1	3.50	33.1	4.110	60.9
2	3.37	29.1	4.105	60.6
3	3.37	29.1	4.104	60.6
4	3.32	27.7	4.106	60.7
5	3.31	27.4	4.103	60.5
6	3.36	28.8	4.110	60.9
7	3.41	30.3	4.106	60.7
8	3.58	35.9	4.113	61.1
TIER (T)	sed = 0.023		sed = 0.0032	
lower	3.27	26.3	4.106	60.7
upper	3.54	34.5	4.108	60.8
PARTITION (P)	sed = 0.010		sed = 0.0014	
not adjacent	3.43	30.9	4.108	60.8
adjacent	3.38	29.4	4.107	60.8

sed = mean standard error of differences.

3.3 Main effects on egg numbers

The main effects of nest group (G), partition (P) and tier (T) on the daily number of eggs were significant ($P < 0.001$) (Table 1). Fewer eggs were laid in nest group 1, for example, than in nest group 8. However, there were significantly more eggs laid in nest group 1 than in nest groups 2 to 6.

Significantly more eggs were laid in the upper tier ($P < 0.001$) than in the lower tier. The influence of the partition was small (1.5 eggs from a total of 30.2 eggs), but significant ($P < 0.05$). In the blocks adjacent to the partition fewer eggs were laid than in the blocks that were not adjacent to a partition. In nest group 8 and to a lesser extent nest group 7, the difference in number of eggs between the upper and the lower tier was less than in the other nest groups (Table 2).

Table 2. Differences in the number of eggs between the nest groups in the upper and lower tier.

	Nest group							
	1	2	3	4	5	6	7	8
Upper Tier	38.5	33.4	33.8	32.1	32.5	34.1	33.8	37.3
Lower Tier	28.8	25.5	25.0	23.8	23.1	24.3	27.1	34.5
Difference	9.7	7.9	8.8	8.3	9.4	9.8	6.7	2.8

Significant ($P < 0.05$) interactions between nest group and tier (Table 2), between nest group and partition and between partition and tier were present. So, for the prediction of the number of eggs for a particular nest group, the exact location was needed.

The regression coefficients for t and $\ln(t)$ were calculated as -0.0068 (se = 0.0011) and 0.3886 (se = 0.0680), respectively, and they were both significant ($P < 0.001$). This indicates a clear change over time in the daily number of eggs, which could be expected.

The interaction between period (PE) and the nest group (G) is shown in figure 4. For each period and nest group the deviations were calculated between the period mean and the number of eggs per nest group. Periods 1 to 3 differ significantly ($P < 0.05$) from periods 4 and 5. The distribution of the number of eggs over the different nest groups within a tier gradually begins to look more and more like the distribution in period 5. From these results, it can be concluded that at least 3 weeks were needed before a stable distribution of the eggs over the nest groups was reached. The interaction between period and tier was not significant.

3.4 Daily variation in mean egg weights

The unexplained variation (ϕ) in mean egg weight was 0.00063 (se = 0.00002). The components of variance σ^2_D, $\sigma^2_{D.G}$ and $\sigma^2_{D.T}$ were estimated as 0.00014 (se = 0.00004), 0.00003 (se = 0.00001) and 0.00019 (se = 0.00003), respectively. The components of variation were low but significant ($P < 0.001$). Other interaction terms were not significant. These results indicate that there is an important daily variation in egg weights and that there are interactions between days and nest groups and between days and tiers. If the daily variation and the unexplained variation were combined, the coefficient of variation for a nest group could be calculated with the formula $CV_{nest\ group} = \sqrt{\sigma^2_D + \sigma^2_{D.G} + \sigma^2_{D.T} + \Phi}$ as 3.1 % (Figure 3). The coefficient of variation for the whole EWACS-row was 1.6 %. These coefficients of variation were much lower than the coefficients of variation for egg numbers.

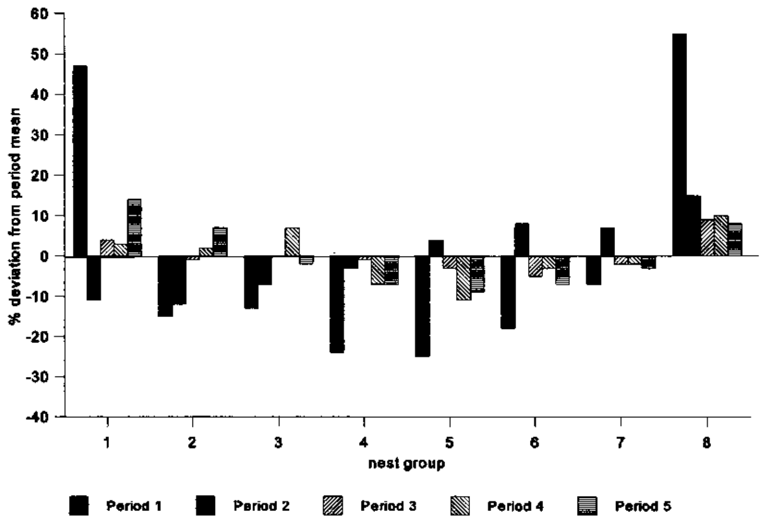

Figure 4. Deviation of the egg numbers per nest group and period relative to the mean egg number per nest group per period.

3.5 Main effects on mean egg weights

Partition, tier and their interactions had no significant influence on mean egg weight. However, the mean egg weight differed significantly ($P < 0.01$) between nest groups. The mean egg weight of nest groups 1, 6, 7 and 8 were higher than the mean egg weight of nest groups 2 to 5. In absolute terms the differences were small, between 0.1 and 0.6 g. Table 1 shows the results of mean egg weight per nest group, tier and partition. Most eggs were laid at the front and at the end of the tier and these eggs were also slightly heavier.

Estimated regression coefficients for t and $\ln(t)$ were -0.00045 (se = 0.00015) and 0.06227 (se = 0.00880) respectively and were significant ($P < 0.001$). Again, as in the case of egg numbers, there was a systematic change with time for mean egg weight. The egg weight gradually increased with time. The effect of the period (PE) was not significant. Only period 2 seemed to show a different distribution of the egg weight over the nest groups within a tier. From this it could be concluded that the pattern of mean egg weight over the different nest groups and tiers was stable from the beginning of the production period.

4. Discussion

4.1 Sources of differences in egg numbers

The number of eggs for a particular nest group depends on the location of that nest group, the level of the tier, the presence of a partition and the number of days in the laying period. Besides, there is also a daily variation in the number of eggs per nest group and there are interactions between days and nest groups and days and tiers. All this specific information from a nest group is necessary to predict reliably the expected number of eggs for that nest group. In other compartments or houses different parameters will probably have to be determined in order to predict the number of eggs in a particular group of laying nests. This makes it difficult to recommend a correct sampling method for the determination of egg numbers, based on data of a limited number of laying nests.

If one wants to detect aberrations within a compartment, based on egg numbers, such as leaking drinking nipples, it is necessary that hens form more or less stable sub-groups that stay at the same place in the compartment. Our egg number data show so much daily variation within a compartment that it is unlikely that sub-groups are formed. This result is in accordance with the results from Appleby *et al.*. (1992) who also found that hens used almost all the available area in a compartment.

In aviary systems hens are housed loose and they have the freedom to choose their laying nest. The results in Table 1 clearly show that hens prefer particular laying nests. The corner nests in nest groups 1 and 8 and the upper tier are preferred. This is in accordance with results of Rietveld-Piepers (1987) and Appleby *et al.* (1988). The difference between the tiers may be explained by their position. Perches are placed in front of the laying nests and hens can land on them (see Figure 1). There are no obstacles above the perches on the upper tier. The perches on the upper tier, however, can create an obstacle to hens wanting to land on the perches of the lower tier. In spite of this, the difference between the 2 tiers is less in blocks 7 and 8 (see Table 2). At the end of a tier hens may choose for a laying nest in a lower tier with relatively greater frequency than selecting a nest towards the middle of the row. In any way, one can conclude that specific circumstances within a compartment influence the data significantly and also affect its usefulness for management.

4.2 Sources of differences in egg weight

The mean egg weight only depends on the nest group itself. Neither tier nor partition have any significant influence on mean egg weight. The variation in egg weight differs from day to day and there is also an interaction between tier and days and between nest group and days. However, the absolute differences are very small. From these results it may concluded that samples of nest groups can be used to determine the mean egg weight of a flock. Averaging over days is less necessary, because the daily variation is small.

The distribution pattern of egg numbers and mean egg weight over the groups of laying nests within a tier is almost the same (Table 1). In nest groups 1 and 8 significantly more eggs were laid and the mean egg weight in these nest groups was also higher than in the other nest groups. A possible explanation for the higher mean egg weight in the corner nests can be found in Douglas *et al.* (1986) and Lee & Choi (1985) who recorded that eggs laid early in the morning are heavier than those laid at other times during the day. Laying starts right after the lights are turned on, and the first hens will choose the most favoured places - the corner nests. This probably means that eggs in the corner nests are laid earlier in the day.

4.3 Use of egg number and egg weight data for daily monitoring of production process

If egg numbers and mean egg weight data are to be used to support decisions in the food control and the early detection of diseases, the normal variation in the data must be lower than the deviation that must be detected. Lokhorst (1995) interviewed some experts in the field of monitoring the production of flocks. This resulted in a list of possible aberrations in the field of climate control, disease control and feed control. Per aberration one or more variables were influenced. The variables egg weight and hen-day egg production could be used to detect 8 different aberrations. These aberrations were respiratory disorder, osteomalacia, digestive disorder, extremely hot day, severe food restriction, severe water restriction, change in food composition and the presence of parasites. A deviation for a specific variable occurred when the real data differed from the expected data. The degree of difference was divided into a starting deviation, an advanced deviation and a serious deviation. The estimated deviations for these 3 classes, and for the 8 aberrations varied between 0.5 % and 9 %. Only a few times the estimated deviation was less than 1 %, and when this occurred it was in the class of a starting deviation. From these results it could be concluded that the normal variation in the egg weight and egg number data may not be higher than 1 %.

4.4 Recommendations

For a block of laying nests, the normal daily variation in mean egg weight was 3.1 %. From Figure 3, it can be concluded that the coefficient of variation of the mean egg weight per block has the same level as the coefficient of variation for egg numbers of the whole compartment, 3.1 and 2.8 respectively.

Egg number data in aviary systems must be based on all nests in a closed area or compartment. Within a compartment there is too much variation to make it worthwhile looking at specific places (Figure 3). The production unit to be monitored should be a compartment. The normal coefficient of variation on the number of eggs will then be in the order of 2.8 %. A lower coefficient of variation can only be obtained by averaging over days. A coefficient of variation of 1 % can be reached if egg number data of the compartment are averaged over 4 d.

Mean egg weight can be determined by taking a sample of eggs and weighing this sample by hand. If eggs from the same nest group, in this case 5 adjoining laying nests, are weighed daily, there will be a coefficient of variation of 3.1 %. If the eggs were taken at random from the whole compartment the coefficient of variation will be slightly higher. Alternatively, an EWACS can be used to determine the mean egg weight of the whole tier, row or compartment. If, for instance, mean egg weight is determined for the whole row, the coefficient of variation is already reduced to 1.6 %. For egg weight it was not possible to calculate the coefficient of variation for the whole compartment, because these data were not gathered. But it may be advised to determine the egg weight for a flock based on a selection of data, e.g. collected by EWACS. Another possibility to reduce the coefficient of variation of egg weight is to average the measured mean egg weight over a few days.

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Chapter 5

Automatic weighing of individual laying hens in aviary housing systems

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Automatic weighing of individual laying hens in aviary housing systems

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Abstract

1.In this study it was investigated, when and where the body weight and the flock-uniformity are to be determined in an aviary system by using automatic weighing systems.
2. An Individual Poultry Weighing System (IPWS) was developed to record time, duration, location and body weight of visits of individual hens to four weighing scales.
3. The number of hens that visited the weighing scales per three-hours period varied significantly ($P < 0.01$) from less than 10 during the dark-period till more than 60 during the light-period.
4. The average number of visits per individual hen was 1.4 and the average number of successful weighings per hen was 0.6 during the light-period.
5. Body weight showed a diurnal rhythm and the difference between the maximum body weight at night and the minimum body weight in the morning was 63 g.
6. The location of the weighing scales influenced the number of visits, number of weighings, mean body weight, flock-uniformity and he duration of the visits.
7. Body weight per three hours period did not differ between individually recognised hens and not individually recognised hens.
8. Flock-uniformity was 2.6 % higher during the light-period if it was based on weighings of identified hen visits.
9. The average duration of the visits to the scales in the middle of the feed tier during the light-period was 63 s.
10. Fifty four percent of the hens that visited the scales during a 24 hours-period, visited them only once.
11. Automatic weighing systems without individual hen recognition can deliver reliable management information on mean body weight and flock-uniformity in aviary systems if the weighing scales are located on the feed tier in the middle of the house and if they are used during the light-period.

1. Introduction

In Western Europe, there has been a substantial amount of research into the development of alternative housing systems for laying hens (Ehlhardt *et al*, 1988; Elson, 1989; Meierhans, 1992; Wegner, 1992; De Wit, 1992). Besides modified cages and percheries, the aviary system is an alternative for cage systems (Appleby *et al*, 1992). In order to use the vertical space in the house the aviary system consists of different levels of tiers. Feed and water are provided on the tiers and perches are placed on the top tier. Laying nests are present, and on the ground floor litter is provided for dustbathing and scratching. Stocking densities of more than 20 hens per m^2 of floor area can be reached with aviary systems, which is comparable with a three tiered cage system (Appleby *et al*, 1992). The group size in cage systems is limited to 4-6 hens per cage, group sizes in an aviary system are limited to the size of the house and can vary from several hundreds (Amgarten & Mettler, 1989) to more than 20 000 hens per group (Blokhuis & Metz, 1992).

The cost price of eggs produced in aviary systems is 8-15 % higher than that of eggs produced in cage systems (Elson, 1992). Important factors are a greater feed consumption, higher housing costs and an increased risk for more variation in the production results (Van Horne, 1991). To control the feed consumption and the egg production, accurate information is required on the production process (Sainsbury, 1992; Lokhorst *et al*, 1996). Body weight is, amongst others, an important variable in the control of the production process (Harms *et a*l, 1984; Turner *et a*l, 1983; Bish *et al*, 1985; Fattori *et al*, 1992ab). Variation in body weight in the flock is represented by the flock-uniformity, which is defined as the percentage of hens whose body weights fall in the interval of plus or minus 10 % of the mean body weight of the flock (Harms *et al*, 1984) .

To determine body weight and flock-uniformity in an aviary system, automatic weighing systems could be used. Advantages of automatic weighing, compared to manual weighing, include a reduced chance of transcription errors, lower labour demand and the hens are not placed under stress (Lott *et al*, 1982; Feighner *et al*, 1986; Turner *et al*, 1983). For broiler breeder hens, laying hens and layer replacement hens in deep litter housing systems it was found that the reliability of the automatic weighing system results are constrained by the technical performance of the weighing equipment and the number of different hens (flock dynamics) using the scale (Blokhuis *et al*, 1988; Turner *et al* 1983). The time of weighing and the location of the weighing scales also influences the results of the automatic weighing systems (Fattori *et al*, 1992b; Turner *et al*, 1983; Savory,1993). Automatic weighing systems are not much used yet in aviary systems, but it may be expected that flock dynamics, time of weighing and location of the weighing scales will have an effect on the weighing results.

The objective of this study is to investigate, when and where body weight has to measured with an automatic weighing system in an aviary system for laying hens, in order to produce reliable information
on mean body weight and flock-uniformity to support daily management.

2. Materials and methods

2.1. Experiment on experimental farm

2.1.1. Animals and housing system

One thousand sixteen weeks old Isabrown-Warren hens were housed in a Tiered-Wire-Floor aviary system (TWF) (Ehlhardt *et al*, 1988). The hens were fed *ad libitum* with a standard layers feed and water was continuously available. The experiment started in the week that the hens were 19 weeks old when the hens had 14 hours of light. From week 20 onwards the hens had 15 hours of light, starting at 6.00 h. Litter was provided on the ground floor. Per square metre ground floor 23.6 hens were housed. In the aviary system 8.3 hens were housed per individual laying nest, 10.0 hens per drinking nipple and 35.6 hens per tube-feeder. Eggs laid in the laying nests were collected once a day, whilst the

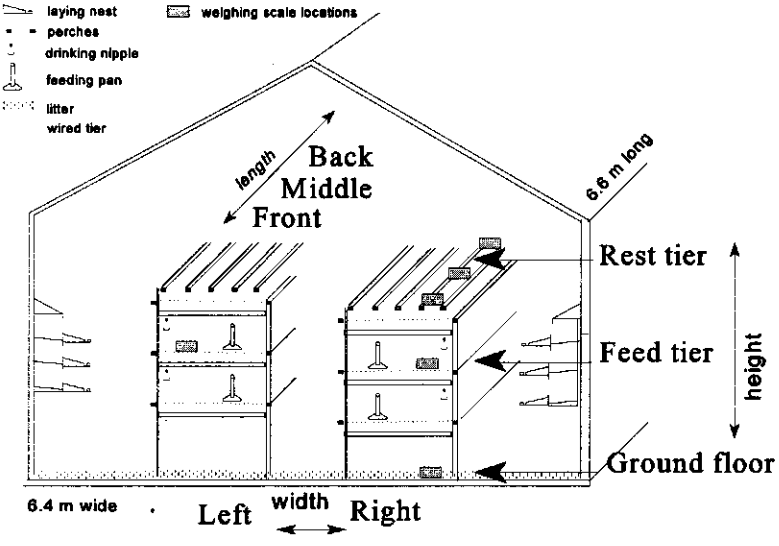

Figure 1. Schematic view of the three dimensions of the Tiered Wire Floor (TWF) aviary system at the experimental farm and the locations (height, length, width) of the weighing scales.

eggs laid on the tiers and in the litter were collected more regularly, particularly during the morning hours.

In terms of spatial use by the hens of the house, three dimensions for the location were distinguished in the TWF system (figure 1). Both the left and the right side of the long axis of the house contained one scaffolding with three tiers. The height in the aviary was divided into the ground floor, where the litter was provided, the two feed tiers and the rest tier. No differences were expected between the two feed tiers. Therefore in this experiment only the upper feed tier was used as a location for the weighing scales. The length of the house was divided into the front, the middle and the back location.

2.1.2 Individual Poultry Weighing System

The Individual Poultry Weighing System (IPWS) was developed to weigh hens automatically and to determine the effects of flock dynamics, time and location of the scales on the mean body weight and flock-uniformity. The IPWS consisted of a registration program on a Personal Computer and four weighing scales with an antenna.

Each individual hen was identified by an electronic transponder that had its own unique number. The transponder was tied to the hens leg by means of a rubber cuff (figure 2). Commercial available antennas (NEDAP-Agri) were placed on top of the weighing scales to read the transponders. A hen was only recognised if it stand on the antenna, or in this case on the weighing scale. Commercial automatic weighing scales (Fancom BV) were used to weigh the hens. Each scale was 20 cm wide, 20 cm long and 8 cm high. The IPWS

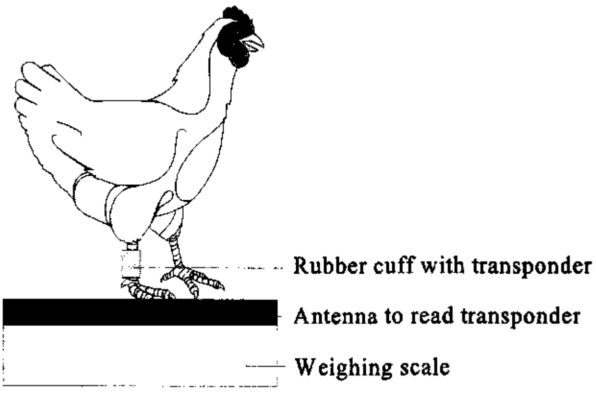

Figure 2 Individual Poultry Weighing System (IPWS)

and the commercial version of the automatic weighing system used the same weighing procedure. The weight of a hen was recorded if the weighing signal was stable, i.e. four consecutive measurements within 1.3 s that did not differ by more than 7.5 g, and were within an interval of plus or minus 30 % of the mean flock weight of the previous day. To correct for dirt and faeces on the scales, they were tared automatically when hens were not present on the scale.

The IPWS recorded the date, hen number, scale number, location number, body weight, the time the visit began and the time the visit ended. Each day a new data-file of the recorded data was created.

2.1.3. Experimental setup

Four weighing scales were available and the experiment ran for five months. Data were collected from 19 to 35 weeks of age. A rotation scheme for scales 1, 2 and 3 was developed for the location of the scales (figure 3). Every Monday, Scales 1, 2 and 3 were moved to another location. Mondays were therefore excluded from the statistical analysis. Scale 4 was fixed on the feed tier at the back of the house throughout the experiment, in order to have a fixed reference point and to get insight in the effect of accustoming to a scale at a certain location.

Data of visits were summarized and categorized according to location and time of day. For data set one, each day was divided into eight three-hour periods. Period 0 was from 00.00 to 03.00 hours and period 21 was from 21.00 to 24.00 hours. The second data set consisted of aggregated data per location per day (24 hours).

	scale number			
age of hens (wk)	1	2	3	4
19 and 27	rest-front	feed-front	ground-front	feed-back
20 and 28	rest-middle	feed-middle	ground-middle	feed-back
21 and 29	rest-back	feed-back (left)	ground-back	feed-back
24 and 30	rest-back	rest-middle	rest-front	feed-back
25 and 31	ground-back	feed-middle (left)	feed-front	feed-back
26 and 32	ground-back	ground-middle	ground-front	feed-back
33, 34, 35	feed-back (left)	feed-middle	feed-middle (left)	feed-back

Figure 3 Rotation scheme for the weighing scales used in the Tiered Wire Floor system of the experimental farm. The location of the scales is given in relation to the width (**left**, **right** [default]), height (**ground**-tier, **feed**-tier, **rest**-tier) and length (**front**, **middle**, **back**) of the house.

2.1.4. Statistical analysis

The general null hypothesis was that hens had no preference for specific locations in the house, that flock dynamics had no effect, and that the time when measurements were taken had no effect on the data collected.

Response variables that were calculated for the 3-hours periods per scale (data set 1) were number of visits, number of weighings, body weight, duration of visits and flock-uniformity. To investigate the flock dynamic effects all hens were recognised individually, but each of these variables was calculated in two ways: from **non-identified** hen visits and from **identified** hen visits. If all visits of an individual hen were seen as independent visits one has a sampling method with replacement. This is comparable with the automatic weighing systems that are used in practice without hen recognition. The non-identified hen visits results are based on these independent hen visits. If all visits of the same hen within the three-hours period are averaged, the results are based on means of identified hens. The last variable was the number of hens paying one, two, three, four, five and more than five visits to the scale per period of 3-hours.

Generalized linear models (GLM) (Genstat 5 Committee,1993), applied to different response variables (E(y)), were used to analyze the data. The model with effects of age (A), scale (S), period (P) and location, subdivided in height (H), length (L) and width (W), that was used for the analysis of data set 1 could be represented by:

$$E(y) = \ln(A) + A + S + P + H + L + W + H.S + H.P + H.L + L.P + \epsilon$$

For the analysis of data set 2 (24 hours period), the period (P) effect and the interactions with period effect were omitted. The same response variables were used as for the three hours periods.

The expected increase of body weight with age was modelled with an incomplete gamma function with variables ln(A) and A, where A is the age of the hens in days. Differences could occur between scales (S) because of the way the scales and antenna were adjusted and because of technical differences.

It was assumed that the number of hens visiting the scales (NHens), the number of visits per hen (VisHen = 0,1,2,.., n) and the number of weighings per hen (WHen = 0,1,2,..,m) were Poisson distributed. A normal distribution was assumed for mean body weight. Relative effects were assumed to be relevant, therefore the linear model for the response variables was studied on the logarithmic scale.

The flock-uniformity ($0 \leq \text{UNI} \leq 100$) and the number of hens that visited the weighing scales either once, twice, three times, four times, five times and more than five times ($0 \leq \text{NHens}_{\text{n\_visits}} \leq \text{NHens}$) were assumed to have a binomial distribution. The linear model was specified at the logit scale, i.e. a logistic regression analysis was performed.

The duration of visits was assumed to show a gamma distribution, indicating that the variance was proportional to the squared mean. Here too, the model was assumed to be linear and relevant on the logarithmic scale, because duration can only be positive.

The models were fitted using the GENSTAT statistical programme (Genstat 5 Committee,1993).

2.2 Experiment on a commercial farm

Data from an experiment on a commercial aviary farm were used to study the consequences of using automatic weighing systems in large aviary houses.

An automatic weighing system (Fancom BV) with four weighing scales was used to register daily mean body weight, flock-uniformity and mean number of weighings per scale in a flock of approximately 16.000 white LSL-laying hens housed in a Righs-Boleg aviary system. The weighing scales were placed on the upper feed tier in the middle of the house. The hens were fed *ad libitum* with a commercial layers feed and water was continuously available. The house was equipped with chain feeders and drinking nipples. The hens received 14h of light, starting at 6.30 h. Litter was provided on the ground floor in the corridors and under the laying nests. Production data were collected daily.

3. Results

3.1. Experimental farm results per 3 hours period

3.1.1. Number of visits and weighings

Age of the hens had no significant effect on the number of visits made by hens. However, the number of weighings per scale was significantly affected by age ($P < 0.001$). As the hens increased in age, there were more weighings. To one of the four weighing scales significantly ($P < 0.01$) less visits were recorded. This was not the scale that was fixed to the same location throughout the experiment. This probably means that there are technical differences between scales, which is also found by, Blokhuis *et al* (1988) and Turner *et al* (1983). Another possibility is that the reach of that antenna was smaller than the reach of the other three antennas.

The mean number of hens that visited the scales in a three hours period, the mean number of visits per hen and the mean number of successful weighings per hen are shown in table 1 per period and location that was divided in height, length and width.

Table 1 Mean number of hens (NHens) per three hours period per scale, with standard error, the mean number of visits per hen (VisHen), the mean number of weighings (WHen) per individual hen and the percentage of hens per number of visits for different periods and locations (height, length, width) of the scales at the experimental farm.

	NHens		VisHen	WHen	% hens per number of visits					
		se			1	2	3	4	5	>5
Period 0	1.9	0.4	5.4	3.0	18.5	10.5	10.9	10.2	1.0	48.3
3	2.0	0.4	5.8	3.8	17.2	10.6	6.9	10.5	7.0	49.5
6	60.8	1.6	1.4	0.6	74.3	16.0	4.9	2.5	0.6	0.8
9	60.1	1.6	1.4	0.7	73.0	17.0	5.1	2.3	0.8	1.0
12	80.4	1.8	1.4	0.5	71.5	17.6	5.8	2.6	0.7	1.0
15	79.8	1.8	1.5	0.6	68.8	18.4	6.6	3.1	1.0	1.7
18	65.2	1.8	1.5	0.7	71.2	16.9	6.1	3.2	0.8	1.1
21	10.0	0.6	1.8	0.7	80.9	10.6	2.3	1.4	0.8	4.8
Height										
ground floor	34.4	1.2	1.4	0.5	67.1	13.2	5.1	2.7	0.5	3.2
feed tier	71.3	2.3	1.4	0.6	72.2	18.2	5.8	2.3	0.8	1.0
rest tier	34.2	1.3	1.6	0.8	71.9	13.8	5.9	5.7	1.0	2.5
Length										
front	38.4	1.5	1.6	0.6	65.3	18.3	7.6	4.9	1.4	2.2
middle	52.0	1.1	1.5	0.6	72.2	16.3	5.7	2.7	0.7	1.6
end	61.6	2.8	1.4	0.6	72.8	17.4	5.1	2.2	0.7	1.2
Width										
left	53.4	2.5	1.5	0.5	71.6	16.2	5.8	3.3	0.8	1.4
right	52.9	1.4	1.5	0.7	71.5	17.3	5.7	2.6	0.8	1.5

The number of hens that visited the scales per three hours period varied significantly ($P < 0.01$) from less than 10 during the dark-periods (0, 3 and 21) till more than 60 during the light-periods (6-18). In the afternoon (period 12 and 15) most visits, about 80, took place. This is in accordance with the results of Fattori *et al* (1992,b) and Savory (1993) who also found an effect of time of weighing. During the light-periods the number of visits per hen and the number of weighings per hen were relatively constant, 1.4 visits per hen and 0.6 weighings per hen. Only during the dark-periods 0 and 3 the mean number of visits and the mean number of weighings per hen increased respectively to more than 5 and more than 3. During these periods most of the hens which visited the scales visited it more than 5 times, while during the light periods 72 % of the hens visited the scale only once per period of three hours. The number of weighings per hen is much lower than the number of visits. About 40 % of the total number of visits resulted in a successful weighing.

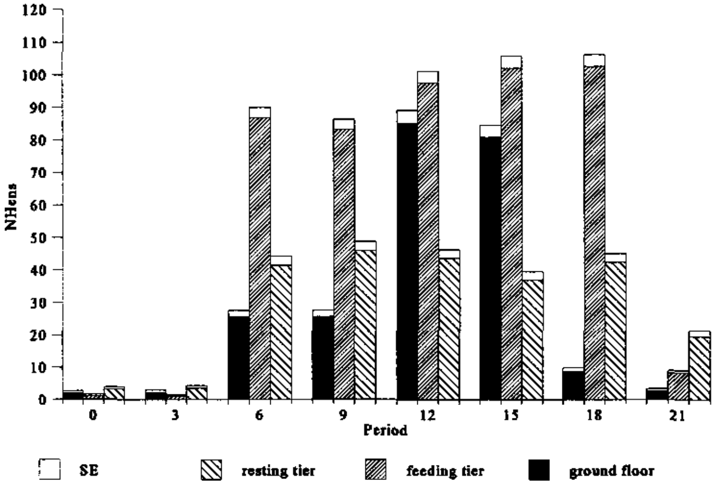

Figure 4 Number of hens (NHens) per 3-hours period, per scale for different heights and periods of the day at the experimental farm.

The number of hens per three hours period per scale varied significantly ($P < 0.001$) for different locations of height and length in the aviary system (table 1). Most hens visited the scales on the feed tier. The number of hens that visited the scales on the ground floor and on the rest tier were almost equal. Most hens visited the scales at the back of the house, followed by the middle and the front of the house, respectively 61.6, 52.0 and 38.4. The difference between front, middle and back are not the same for the ground floor, the feed tier and the rest tier. The mean number of visits per hen varied from 1.4 till 1.6 for different heights and lengths. The mean number of weighings per hen was 0.5 on the ground floor and 0.8 on the rest tier. No difference between front, middle and back was found for the number of weighings per hen. There were fewer weighings ($P < 0.01$) per hen in the left-hand section of the compartment than in the right-hand section. The number of visits that on the left side did not differ from the right side.

Figure 4 shows the number of hens visiting the scales for different combinations of period and height. The number of hens on the feed tier and on the rest tiers are relatively constant during the light-periods. The number of hens on the ground floor increased during the afternoon when the hens dustbath and scratch in the litter.

3.1.2. Body weight

As was expected body weight increased significantly ($P < 0.001$) with increasing age of the hens. The mean body weights for non-identified hens and the difference between body

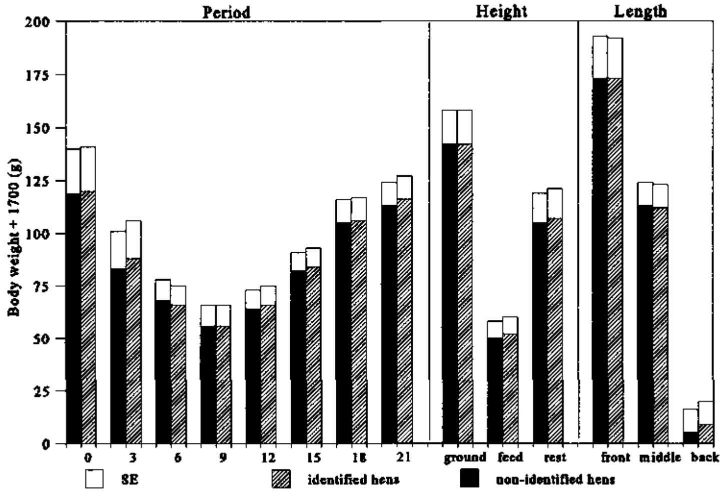

Figure 5 Body weight for identified and non-identified hens, with their standard errors, for different periods, heights and lengths at the experimental farm.

weight for non-identified and identified hens are shown in figure 5 for different periods and locations.

The difference between the body weight for non-identified hens and the body weight for the identified hens was negligible. The mean body weight per three hours period varied between 1756 g (period 9) and 1819 g (period 0), indicating that the difference between maximum and minimum body weight in a twenty four-hour period was 63 g. Towards the end of the night and during the morning the hens loose weight, but they recover it in the course of the afternoon and evening. This diurnal pattern of the body weight, however, differs for the height- (figure 6) length- and width location ($P < 0.001$). Body weight on the feed tier differs in period 0, 3 and 21 from the diurnal pattern of the body weight on the ground floor and the rest tier. Body weight seems to be heavier amongst hens on the ground floor during the day-time (figure 6).

Body weight results from hens that visited the scales once, twice, etc. per three hours period showed that in periods 0 and 3 the mean body weight of hens visiting the scale more than once was more than 5 % lower ($P < 0.05$) from the mean body weight of the hens that visited the scales only once. In the other periods deviations were no more than 2 %.

3.1.3. Flock-uniformity

The flock-uniformity for non-identified hens and for identified hens for different periods and locations are shown in figure 7.

The flock-uniformity varied significantly ($P < 0.01$) between periods and the maximum flock-uniformity was 94.2 % in period 0 and the minimum flock-uniformity was 62.7 % in period 15. During the light-periods the flock-uniformity was relatively constant, 64.2 %,

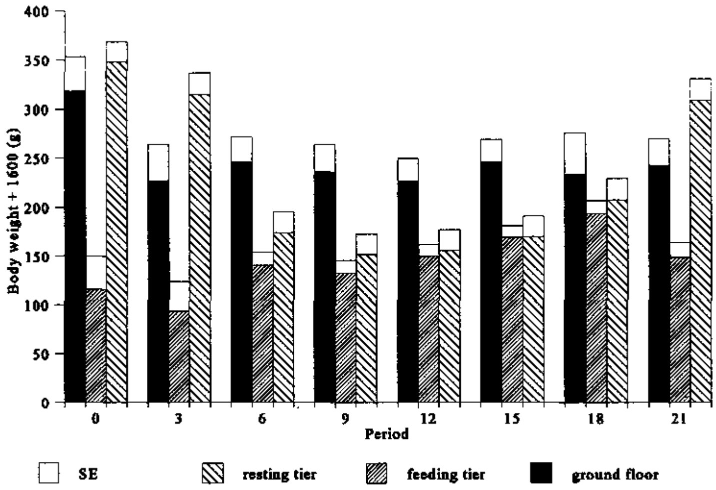

Figure 6 Body weights of non-identified hens for different heights and 3-hours periods of the day in the experimental farm.

and the flock-uniformity for the non-identified hens was about 2.6 % lower than the flock-uniformity for the identified hens.

The flock-uniformity varied significantly ($P < 0.01$) for the different length locations. As with body weight, uniformity differs between combinations of period and length and combinations of length- and height locations. As was the case with mean body weight, uniformity also decreased from the front of the aviary to the back of the aviary house.

3.1.4. Duration of visits

The duration of the visits depended on the period and locations ($P < 0.001$). During the light-periods the duration of the visits was much lower, 68-80 s, than during the dark-periods, 366-1386 s. The duration of the visits for different combinations of height location and period are shown in figure 8.

The longest daytime visits occurred on the rest tier, followed by the feed tier and the ground floor. The mean duration during the light-periods on the feed tier was 63 s.

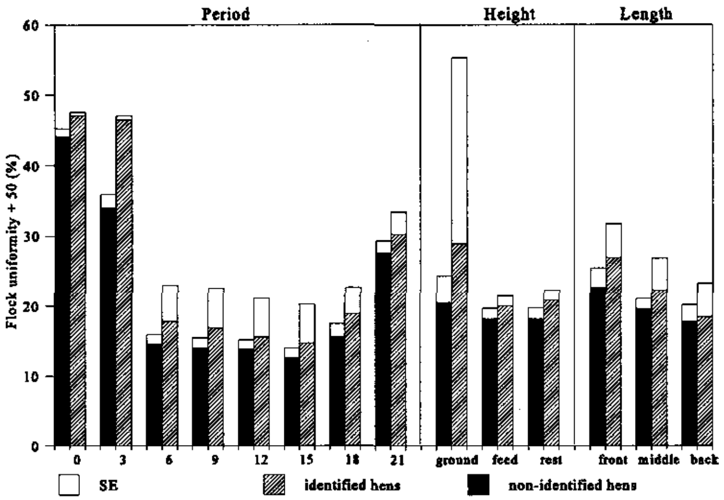

Figure 7 Flock-uniformity for identified and non-identified hens, with their standard errors, for different periods, heights and lengths at the experimental farm.

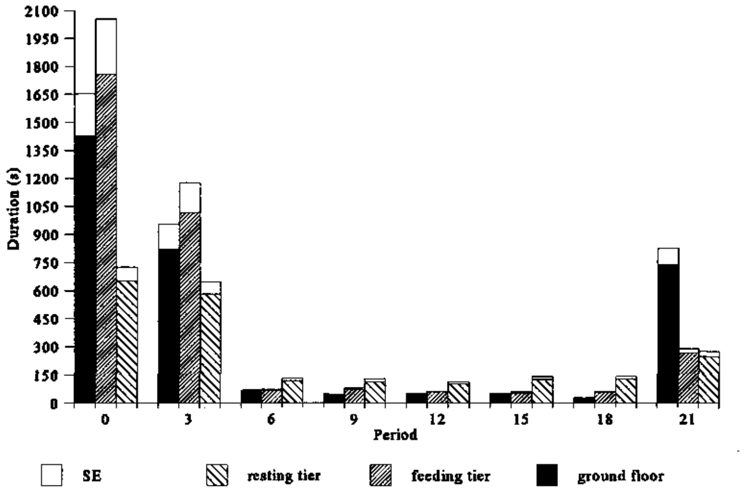

Figure 8 Mean duration (s), with standard errors, of visits per three hours period per scale for different period and height combinations at the experimental farm.

3.2 Experimental farm results per day (24 hours)

Table 2 shows the number of hens per day visiting the scale in the middle of the house on the feed tier. From the 1000 present hens in the house 341.1 different hens per day visited this location. Fifty four percent of these hens visited the scale only once, twenty percent twice and twenty four percent more than twice, which resulted in a total of 681.2 visits. Only 242.4 of these visits resulted in a successful weighing, while the mean duration of each visit was 76.6 s. The mean daily body weight and flock-uniformity were respectively 1775,5 g (se = 20.7) and 63.7 % (se = 1.2).

Table 2 Mean number of hens (NHens), number of visits (NVis), number of weighings (NWeigh), body weight (BW), flock-uniformity (UNI) and duration (Dur), with standard errors, per day for the weighing scales that were located on the feed tier in the middle of the house at the experimental farm and the percentage of hens per number of visits.

	mean	se	% hens per number of visits					
			1	2	3	4	5	>5
NHens	341.1	14.5	54.1	21.6	11.3	6.1	2.8	4.6
NVis	681.2	34.3						
NWeigh	242.4	16.1						
BW (g)	1775.5	20.7						
UNI (%)	63.7	1.2						
Dur (s)	76.6	11.2						

3.3 Commercial farm results per day

Figure 9 shows the mean daily number of weighings per scale in the commercial aviary house. The mean number of weighings per weighing scale for the whole recording period was 231 (sd=42.1, n=203), but it was not constant during the whole recording period.

4. Discussion and conclusions

4.1 Reliability

It can be concluded that, in general, automatic weighing systems deliver useful information on mean body weight and flock-uniformity that can be used for management support in an aviary system for laying hens. Although the type of aviary system, the type of hens and the group sizes were different between the commercial farm and the experimental farm, the number of weighings per scale per day were of the same order (table 2, figure 9). From this it could be concluded that the data from the experimental farm could be representative for commercial sizes of aviary farms. The weighing scales in the middle

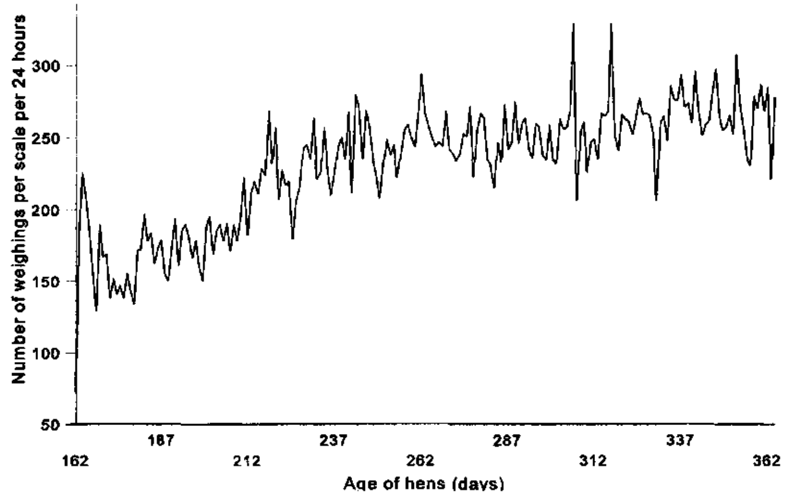

Figure 9 Mean daily number of weighings per weighing scale at the commercial farm.

of the feed tier were used for about 60 % of the day (table 2). If one bears in mind that the number of visits during the dark-periods (table 1) were much lower than during the light-periods one could conclude that the scales were used almost continuously during the light period. Of the 681.2 (table 2) visits only 242.4 resulted in a successful weighing. This may be caused by movements of the hens. According to the used weighing algorithm, which also was used in the commercial version, hens should stand still for approximately 1.3 s before a weighing is accepted, which is probably too long for a hen. Besides, as our results show there can also be differences between weighing scales, which is in accordance with the results of Blokhuis et al (1988) and Turner et al (1983). However, it can be concluded that there is a lot of room for improvement, in order to get more weighings per scale.

Based on the standard deviation, a confidence limit of 95% and an acceptable deviation it is possible to calculate the number of weighings needed (table 2) to get the required information. If an acceptable coefficient of variation for the mean body weight is 1 %, the number of weighings needed will be 1259 per day, which means 5.2 weighing scales per group of hens. If 1.5% and 2% are acceptable coefficients of variation, then 2.3 respectively 1.3 scales are needed to determine the mean body weight reliably per group of hens. To determine the flock-uniformity reliable 5.7, 2.5 and 1.4 scales respectively were needed for acceptable absolute deviations in flock-uniformity of 1, 1.5 and 2%. These number of weighings scales needed in an aviary house are based on the data in the experimental farm. However, it can be expected that this will also be valid for commercial sizes of flocks, because the number of weighings in the commercial farm were almost the same as in the experimental farm.

Individual hen recognition was used to determine whether or not data recorded by the automatic weighing system were representative of this group of hens as a whole. Individual hen recognition was a unique way of determining whether some hens visited the scales more frequently than others and whether or not this affected weighing results. The difference between the mean body weight from the identified and the non-identified hens was negligible. Flock-uniformity in the light-periods was slightly lower - about 2.6 % - when individual hen recognition was not used. This can be explained by averaging all the weighings made of one hen. The sample of weighings consisted of many different hens (table 1, 2) and the difference in mean body weight between the non-identified hens and the identified hens was negligible. So, one can conclude that the automatic weighing systems can be used successfully in aviary systems without individual hen recognition.

4.2. Period

It can be concluded that mean body weight and uniformity are best determined during the light period because substantially more weighing took place then and many different hens visited the scales. Our results show that the time of weighing influences the weighing results, which is in accordance with results of Fattori et al (1992) and Turner et al (1983).

More hens visit the scales in the light-periods 6, 9, 12, 15 and 18 than in the dark-periods (0, 3, 21) (table 1). The number of visits and the number of weighings per hen respectively, were 1.4 and 0.6 during the light-periods. In the dark-periods much more visits and weighings per hen were recorded, because a few hens came onto the scales many times (table 1).

There were differences in the light period visiting pattern recorded for different height levels. This can be explained by the hens' light period movements. Normally hens sleep on the rest tier and in the morning they moved around the whole aviary system. In the afternoon they dustbath and scratch in the litter provided for them on the ground floor. These patterns were reflected in the visiting frequency (figure 4).

Mean body weight showed a diurnal pattern (figure 5). At night the hens were heaviest. At the end of the night and in the morning they defecated, laid an egg, ate and drank. The minimum daily weight was recorded during the morning. According to Savory (1993) laying hens ate relatively more at the end of the day and it is then that the new egg is formed. This explains the increase in mean body weight during the afternoon and night. The difference between maximum and minimum body weight during the course of a day was 63 g. This corresponds with the weight of an egg, but components such as water consumption (240 cl), feed consumption (110 g) and the excretion of faeces (170 g) play also a roll in the daily weight turn-over of a hen. The diurnal pattern of the body weight made it difficult to perform good manual control measurements, because they are performed on a specific time of day. It was therefore impossible to weigh the same hens manually and automatically. Differences in mean body weight between the light and dark period could not be attributed to differences in the number of weighings. At night relatively more weighings per hen took place (table 1), and these frequently weighed hens were lighter then the hens that were weighed once or twice. So, at night there will be sooner an underestimation of the mean body weight than during daytime.

4.3 Location

A good location for placing the weighing scale in an aviary system for laying hens was on the feed tier in the middle of the house.

The location of the weighing scales influenced the number of visits, number of weighings, mean body weight, uniformity and the length of the visits. More hens visited the scales on the feed tier than on the rest tier or the ground floor (table 1). The mean body weight on the feed tier seems to be lower than the weights recorded on the other tiers (figure 5), but the main reason for this were the lower weights in the dark periods 0, 3 and 21 (figure 6). The mean body weights on the ground floor differed from the light period weights recorded on the other two levels. Flock-uniformity on the rest and feed tier were almost the same during the light period.

Mean body weight and flock-uniformity decreased from the front of the house to the back of the house. Fattori et al (1992) also found a location effect between the front and the end of the house. The feeding system in the aviary system, may have be responsible for this location effect, because the tube-feeders at the front of the hen house were filled first and the tube-feeders at the back of the aviary were filled last. The length location effect was not the same for the number of visits and the number of weighings. Most visits to the feed tier took place at the back of the house whilst on the rest tier most visits were recorded at the front of the house. It is possible that the weighing scale at the back of the feed tier was favoured because it never changed position. To correct for differences in the length of the house it is best to place the weighing scale in the middle, although most weighings were recorded at the back of the feed tier. There were no significant differences between the number of visits to the scales between the left and the right side of the aviary house. So, scales could be placed either at the left or right side of the house.

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Chapter 6

Mathematical Curves for the Description of Input and Output Variables of the Daily Production Process in Aviary Housing Systems for Laying Hens

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Mathematical Curves for the Description of Input and Output Variables of the Daily Production Process in Aviary Housing Systems for Laying Hens

C. Lokhorst

Abstract

The objectives of this study were 1) to draw up appropriate mathematical curves that describe the daily production process by the input variables daily feed consumption, water consumption, ambient temperature, and output variables hen-day egg production, egg weight, second grade eggs, floor eggs, cumulative mortality, body weight and flock uniformity, and 2) to get insight into the daily variation in these variables, in order to support the poultry farmer with an aviary housing system in his daily management. Literature and research data attained from six unmolted flocks that were housed in aviary systems were used to formulate the mathematical curves. The curves were a function of the number of days in the laying period. The curves for the cumulative mortality, hen-day egg production, egg weight, body weight, and percentage of floor eggs described the individual flocks results well ($.72 < R^2_{adj} < 1.00$*). The coefficients of determination for the feed consumption, water consumption, flock uniformity, and the percentage of second grade eggs were in general low (*$.33 < R^2_{adj} < .54$*), which implies that the form of the curve differs between flocks. Egg weight, body weight, cumulative mortality and hen-day egg production had the lowest minimum coefficients of variation (.8 to 1.9), followed by feed consumption, water consumption, and flock uniformity (2.8 to 3.6). The ambient temperature, percentage floor eggs, and percentage of second grade eggs had the highest minimum coefficients of variation (4.8 to 9.1).*

(Key words: mathematical curve, egg production, aviary system, laying hen, variability)

1. INTRODUCTION

Most laying hens are housed in battery cages with a maximum of 450 cm^2 floor area per hen (NN, 1986). Cage systems have strong advantages above alternative housing systems, especially in terms of economics, pollution control, and working conditions (De Wit,1992; Appleby *et al.*, 1994). In terms of welfare aspects, the alternative housing systems are preferable (De Wit,1992). Aviary housing systems are developed to provide such an alternative (Ehlhardt *et al.*, 1988; Amgarten and Mettler, 1989; Elson, 1989; Appleby *et al.*, 1992; Blokhuis and Metz, 1992; Hansen, 1994; Blokhuis and Metz, 1995). In aviary systems hens have more space (approximately 1,000 cm^2 available area per hen) and freedom to move in all three dimensions of the house, they can scratch and dustbathe in the litter that is provided on the floor, and they can use laying nests and perches.

At the current state of development of alternative housing systems, production costs, labor requirements, required management skill and required veterinary supervision are all higher than in cage systems (Van Horne, 1991; De Wit,1992; Elson, 1992; Blokhuis and

Metz, 1995). In floor-housed flocks, there is a higher risk of infectious diseases, endoparasites (round and flat worms), ectoparasites (mites), pathological conditions of the feet, and cannibalism (Appleby *et al.*,1994). In cage systems, there is a higher risk for fatty livers and osteoporosis (Appleby *et al.*,1994). To support the aviary farmer in his daily management, Lokhorst *et al.* (1996) suggested to develop computer-based tools to monitor and control the three main critical success factors (CSF) feed consumption, ambient temperature, and disease detection. An expert system prototype has been developed by Lokhorst (1995) to monitor the three CSF. The expert system prototype compares daily data on feed consumption, water consumption, hen-day egg production, second grade eggs, floor eggs, egg weight, body weight, flock uniformity, cumulative mortality, and ambient temperature with a standard. Deviations of different variables from the standard are used to detect aberrations in the three mentioned CSF (Lokhorst, 1995).

Available standards from breeding and feed companies only have weekly data on a limited number of variables, whereas daily data for all mentioned variables are used by the expert system prototype to monitor the daily production process. Because the intention is to use the expert system on farms, it is necessary to have farm specific standards, in which the farm specific circumstances can be incorporated. So, for each variable that is used in the expert system prototype a mathematical curve must be developed.

The production of eggs can be seen as a process with input variables feed consumption, water consumption, and ambient temperature and the output variables egg production (hen-day egg production, egg weight, second grade eggs, floor eggs), mortality, and growth (body weight, flock uniformity). The poultry farmers management skills are used to manage this production process and he continually looks for deviations in that process. Despite his management skills the production process is sometimes unpredictable. According to Deming (1986) two sources of variation can be distinguished: 1) normal process variation and 2) exceptional process variation. Normal process variation is inherent to the system and permanently present and its influence on the production process is small and unpredictable. Normal process variation in general can not be assigned to one specific cause. Exceptional process variation has an external cause, occurs one at a time, is incidental and local, and has a large influence on the the production process. In order to detect exceptional process variation, it is important to know the normal process variation of the production process. In other words, the manager should not be worried about normal variation in the production process.

The objectives of this study are 1) to formulate appropriate mathematical curves that describe the input and output variables of feed consumption, water consumption, ambient temperature, hen-day egg production, egg weight, second grade eggs, floor eggs, cumulative mortality, body weight, and flock uniformity, and 2) to get insight in the daily variation in these variables. The mathematical curves can function as a standard that is based on daily production data, and they can be used by the poultry farmer to detect aberrations (exceptional process variation) in the production process in aviary housing systems.

Table 1. General data on the aviary flocks. TWF = Tiered wire floor system

Flock no.	Age of hens at the start in the laying house	Number of hens at the start of the laying cycle (age = 141 days)	Type of aviary system	Breed of hens
	(d)	(no)		
1	119	20866	TWF	Bovans
2	110	20990	TWF	LSL
3	118	23094	Multifloor	LSL
4	122	25750	TWF	Bovans
5	122	15956	Righs Boleg	LSL
6	122	15900	Righs Boleg	LSL

2. MATERIALS AND METHODS

2.1. Animals and Data Collection

Data from six unmolted flocks (Table 1) were used to fit the parameters for the mathematical curves for hen-day egg production, egg weight, feed consumption, water consumption, second grade eggs, floor eggs, body weight, flock uniformity, and cumulative mortality. The mean and standard deviation per flock were determined for the ambient temperature. Two flocks consisted of white Bovans and the other four flocks consisted of white Lohman (LSL) hens. All flocks were housed on farms with an aviary system. The Tiered Wire Floor (TWF), Multifloor, and Righs Boleg aviary systems are described in Blokhuis and Metz (1995). Process computers were used to register daily the mean ambient temperature, the feed consumption and the water consumption. During the first 50 d of the laying cycle of Flock 1 no feed and water consumption data were collected. The poultry farmers recorded daily the mortality and the number of first grade, second grade, and floor eggs. Average egg weight was determined by the poultry farmer once a week for Flocks 1 to 4 and daily for Flock 5 and 6 by weighing a pile of six egg trays with a total of 180 eggs. An automatic weighing system with four scales, placed in the middle of the feed tiers, was used to determine the daily body weight and the flock uniformity in Flock 5 and 6. Body weight and flock uniformity data for the first 85 d of the laying period of Flock 6 were not present.

2.2. Mathematical Curves

Literature and research data attained from the six flocks, housed in aviary systems, were used to formulate mathematical curves that describe the input and output variables of the production process. The variables feed consumption, water consumption, hen-day egg production, egg weight, second grade eggs, floor eggs, body weight, flock uniformity and cumulative mortality are described as a function of age (t), where t represents the number of days in the laying period, which is presumed to start at an age of 141 d (Siplu, 1990). Cumulative mortality is based on the number of housed hens at the start of the laying period and the other functions are based on the number of hens present. The ambient temperature is presumed to be relatively constant during the whole laying period (Lokhorst *et al.*, 1996).

2.3. *Statistical Analysis*

The nonlinear regression method of the statistical program SPSS® (Norusis, 1992) was used to fit the parameters of the mathematical curves for the different variables. Fitting was done per flock. To get an overall fit of all flocks, data of the six flocks were combined to one data set. Because of the small number of flocks, no flock, housing system or hen type effects were analyzed, and also all the fitting results of the different flocks were given separately. The coefficient of determination (R^2_{adj}) and the variance (σ^2) were used as goodness of fit measurements. Starting values were determined by using simple mathematical methods, such as the determination of derivatives and the graphical determination of slopes and limits.

3. RESULTS

3.1. *Mathematical Curve Formulation*

3.1.1. Hen-day Egg Production.

The hen-day egg production is calculated as the number of eggs produced per day divided by the number of present hens. Cason and Britton (1988) compared 1) the model of Adams and Bell (1980) $P=.07(1/(.01 + ar^{(x-b)})-c(x-d))$, 2) the compartmental model of McMillan (McMillan, 1981; McMillan *et al.*, 1986; Yang *et al.*, 1989) $P = a(e^{-bx})(1-e^{-c(x-d)})$, and 3) a logistic model developed by themselves $P=a(e^{-bx})(1/(1+e^{c+dx}))$. These three models describe the weekly egg production (P), where x is the age of the flocks in weeks, e is the base of natural logarithms and parameters a, b, c, d are constants to be determined by a least squares error nonlinear curve-fitting program (Cason and Britton, 1988). Adams and Bell (1980) modelled the egg production as the difference between a sigmoid increase (a logistic growth curve), and a linear decrease and they assumed a theoretical maximum egg production of 100%. The compartmental model of McMillan (1981) is divided into two components, the percentage of hens that start laying and the average egg production of these hens. Both components are functions of the age of the hens. A normal distribution is assumed for hens that start laying, which is described by a logistic curve representing the sexual maturity. It is also assumed that egg production starts at a high level (for instance 80 or 90%), quickly raises to a maximum and then gradually diminishes. Cason and Britton (1988) tried to combine the decreasing term of the compartmental model of McMillan (1981) and an increasing term representing a logistic growth curve similar to the increasing term of Adams and Bell (1980). The conclusion of Cason and Britton (1988) was that the Adams and Bell (1980) model fitted best to their data, followed by the logistic model and the compartmental model.

For the mathematical curve that describes the daily hen-day egg production in an aviary system, the following assumptions are made. A normal distribution is assumed for hens that start laying. Therefore a logistic growth curve, as described by Adams and Bell (1980), is used. Adams and Bell (1980) assumed a theoretical maximum production of

100% and a linear decrease of the egg production when hens become older, but this can be doubted, as suggested by Yang *et al.* (1989). Plots of our own data show a quick increase in the hen-day eggs production, a more or less stable production followed by a nonlinear decrease. Therefore a second order polynomial is used to describe the gradual decrease in egg production. The notation for the hen-day egg production, becomes now:

$$Y_{hen\_day\_egg\_production}\,(percentage) = \frac{100}{1 + a * r^{t}} - (b + c * t + d * t^{2})$$

The logistic part is described with parameters a (a>0) and r (0 < r < 1) and the second order polynomial is described with parameters b, c and d. The hen-day egg production at the start of the laying period is determined by parameters a and b. The time between the start of the laying period and the day the maximum production is reached, is influenced by parameter r. The results of the second order polynomial are subtracted from the asymptote of the logistic growth curve part, which represents the theoretical maximum hen-day egg production. The realized maximum hen-day egg production therefore depends on all parameters. The persistency of the hen-day egg production is described as a gradual decrease with parameters c and d.

3.1.2. Egg Weight.

Egg weight is asymptotically related to age, and this can be described with a restricted growth curve (Adams and Bell, 1980; Minvielle *et al.*, 1994). Although the formula of Minvielle *et al.* (1994) is somewhat different from that of Adams and Bell, the basic principles are the same. The maximum egg weight is the asymptote and the initial egg weight is described with a parameter that is subtracted from the maximum egg weight. The growth rate is described with parameter r. Plots of our own data show the same pattern. Therefore the next mathematical curve is used to model the daily egg weight in aviary systems for laying hens:

$$Y_{egg\_weight}\,(grams) = a + b * r^{t}$$

The parameter a in the formula expresses the asymptote of the maximum egg weight and b must be subtracted from a to determine the initial egg weight at the start of the laying period. Parameter r (0 < r < 1) is responsible for the growth rate.

3.1.3. Floor Eggs.

In literature no mathematical curve is found that describes the relation between age and the percentage of floor eggs. Plots of our own data show that the percentage of floor eggs starts at a relative high level and that there are large differences between flocks (3 to 20%). At the start of the laying period the hens must adjust to the laying nests and the egg production is also low. Right after the start of the laying period a quick decrease in the percentage of floor eggs is seen, which is sometimes followed by a gradual increase and sometimes it stays at a stable level. The percentage of floor eggs is modelled with a combination of an exponential decreasing component and a second order polynomial. The second order polynomial can be used to model different combinations of decreasing and increasing components. The mathematical curve for the percentage of floor eggs is expressed with the following formula:

$$Y_{floor\_eggs}\,(percentage) = a * e^{-b*t} + c * t + d * t^2$$

The percentage of floor eggs at the start of the laying period is described with parameter a ($a > 0$). The initial fast exponential decrease of the percentage of floor eggs is described with parameter b. The combinations of gradual increase and decrease of the percentage of floor eggs are expressed by parameters c and d.

3.1.4. Second Grade Eggs.

Adams and Bell (1980) and Van Horne *et al.* (1991) proposed a linear function for the quantification of the second grade eggs. Interpolation between an initial value and a value for the percentage of second grade eggs at the end of the laying period is used to calculate the percentage of second grade eggs. Sugimoto *et al.* (1986) propose a quadratic function for the percentage of second grade eggs. Our own data suggest a quadratic relationship between the age of the hens and the percentage of second grade eggs. This relationship can be described with a second order polynomial. The mathematical curve for the second grade eggs then becomes:

$$Y_{second\_grade\_eggs}\,(percentage) = a + b * t + c * t^2$$

The initial percentage of second grade eggs at the start of the laying cycle is represented by parameter a. The combinations of the gradual increase or decrease is described with parameters b and c.

3.1.5. Feed and Water Consumption.

In literature no appropriate mathematical curve are found to describe the relation between feed consumption and age and between water consumption and age. Van Horne et al. (1991) interpolates between six feed consumption data that are representative for the whole laying period. Our own daily data of the feed- and water consumption show much variation, but the main pattern for the two is the same. In the begin of the laying period feed- and water consumption gradually increase, which can be represented by a restricted growth curve. After a while the feed- and water consumption per flock show different patterns. These pattern show a gradual increase or decrease or combinations, and these can be described with a second order polynomial. The same mathematical curve is used to describe feed- and water consumption, but separately fits were made because feed- and water consumption were different variables. The mathematical curve to describe the daily feed- and water consumption therefore becomes:

$$Y_{feed\_or\_water}\,(grams\ or\ centiliters) = \frac{a}{1 + b * e^{-a*c*t}} + d * t + e * t^2$$

The first part of the formula represents the restricted growth curve and the second part of the function represents the second order polynomial. Parameter a represents the horizontal asymptote of the restricted growth curve. Parameter b represents, together with parameter a, the feed or water consumption at the start of the laying period ($Y_0 = a/(1+b)$) and parameter c, together with parameter a represents the speed of the increase in feed and water consumption in the restricted growth phase. Parameters d and e determine whether feed and water consumption gradually increase or decrease during the rest of the laying period.

3.1.6. Body Weight.

Graphs of the body weight of different breeds of laying hens showed, like the feed- and water consumption, a logistic growth curve and a linear increase. Our own data show the same growth. Therefore, the next mathematical curve is used to represent the daily body weight of the hens:

$$Y_{body\_weight}\,(grams) = \frac{a}{1 + b * e^{-a * c * t}} + d * t$$

3.1.7. Flock Uniformity.

In literature no mathematical curve is found that represents the flock uniformity. Our own data suggest a quadratic relationship between the age of the hens and the flock uniformity. This relationship can be described with a second order polynomial. Therefore, the mathematical curve for the daily flock uniformity becomes:

$$Y_{flock\_uniformity}\,(percentage) = a + b * t + c * t^2$$

The flock uniformity at the start of the laying period is represented by parameter a. The gradual increase or decrease of the flock uniformity during the rest of the laying period is determined by parameters b and c.

3.1.8. Cumulative Mortality.

Adams and Bell (1980) and Van Horne *et al.* (1991) calculated the cumulative mortality by interpolating data of the first and last week of the laying period. Based on our own data a quadratic increase of the cumulative mortality seems more suitable. If the number of hens at the start of the laying period is known, the number of hens present on a certain day in the laying period can be calculated with the next mathematical curve for the cumulative mortality:

$$Y_{cumulative\_mortality}\,(percentage) = a * t + b * t^2$$

The parameters a and b respectively are expressing the linear and quadratic increase in the cumulative mortality of the hens during the laying period.

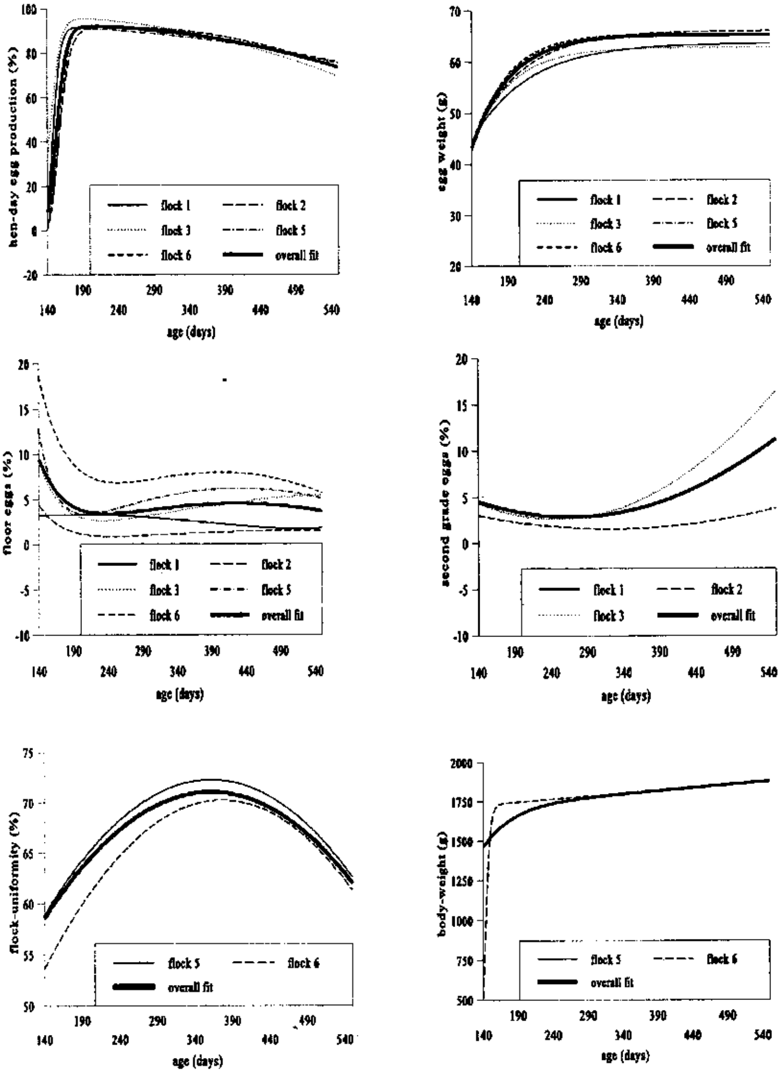

Figure 1. Mathematical curves for the hen-day egg production, egg weight, floor eggs, second grade eggs, flock uniformity and body weight as a function of age for different flocks that are housed in an aviary system for laying hens

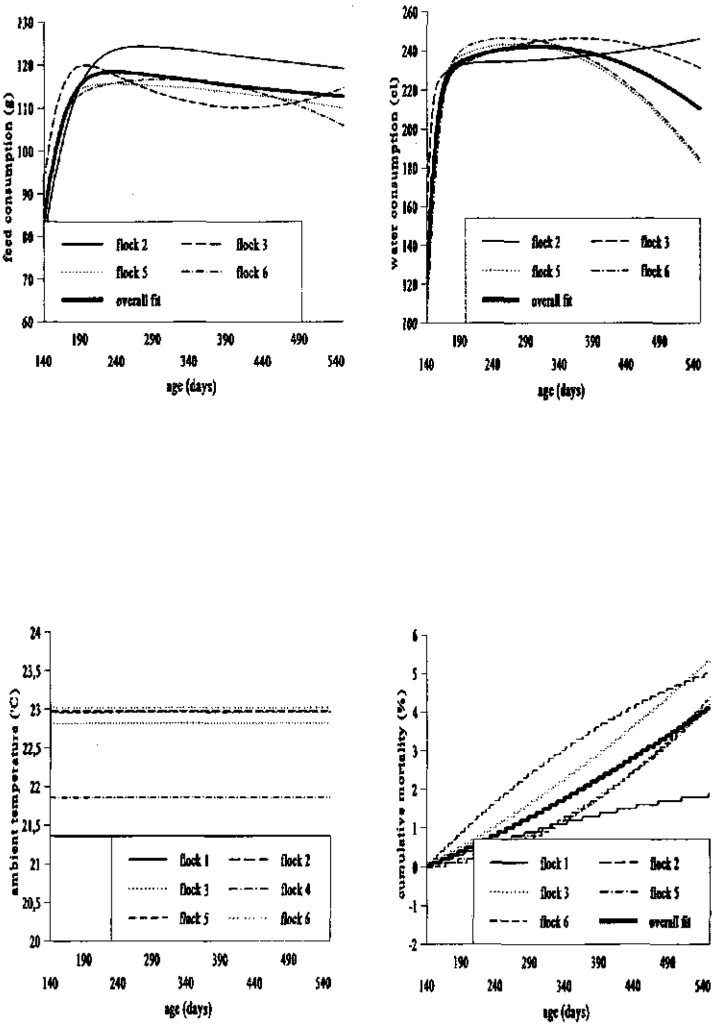

Figure 2. Mathematical curves for feed consumption, water consumption, ambient temperature, and cumulative mortality as a function of age for different flocks that are housed in an aviary system for laying hens

3.2. Mathematical Curve Fitting Results

Figure 1 and 2 show the graphical representation of the mathematical curves. The parameter fits for each mathematical curve are presented in Table 2 to Table 9. The results of Flock 4 are excluded from the overall fit, because a major aberration in the production process occurred at an age of 203 d. This aberration had a temporary effect on feed and water consumption and a permanent effect on the hen-day egg production.

Table 2 Parameter fits for the hen-day egg production (%) for six separate aviary flocks and the overall fit of the flocks with their asymptotic standard error (ase).

$$Y_{hen\_day\_egg\_production} = \frac{100}{1 + a * r^{t}} - (b + c * t + d * t^{2})$$

Parameters	Overall fit		Flock number					
		ase	1	2	3	4*	5	6
a, %	5.274	.247	4.480	7.858	1.864	.761	10.218	13.458
r, ln%/lnd	.871	.003	.832	.882	.872	.794	.847	.859
b, %	7.506	.522	8.241	10.365	3.631	13.638	7.944	6.784
c, %/d	-.005	.006	-.007	-.041	.006	-.052	.011	.011
d, %/d^2	1.252E-4	1.317E-5	1.260E-4	1.976E-4	1.443E-4	3.273 E-4	6.772E-5	7.816E-5
R_{adj}^2	.866		.907	.989	.964	.806	.973	.969
σ^2	24.012		11.631	2.640	2.933	19.888	5.515	7.653

* excluded from the overall fit

Table 2 shows the parameter fits for the hen-day egg production for six flocks and for the overall fit of the flocks. From variance values in Table 2, one can see that there is not only variation within flocks, with a maximum of 11.631 for Flock 1, but there is also a lot of variation between flocks (24.012). The coefficients of determination per flock are high ($R^2_{adj} > .9$), except for Flock 4, which can be explained by the aberration that occurred.

Table 3 shows the parameter fits for the egg weight for six flocks and for the overall fit of the flocks. The coefficients of determination per flock and for the overall fit are greater than .9. Variation in Flocks 1 to 4 is lower than variation in Flocks 5 and 6. Probably this is caused by the interval in which the data are gathered. Egg weight data for Flock 1 to 4 are gathered only once a week, whereas egg weight data for Flocks 5 and 6 were gathered daily.

Table 3 Parameter fits for the egg weight (g) for six aviary flocks and the overall fit of the flocks with their asymptotic standard error (ase).

$$Y_{egg\_weight} = a + b * r^{t}$$

Parameters	Overall fit		Flock number					
		ase	1	2	3	4*	5	6
a, g	65.277	.070	63.665	66.104	62.844	61.828	65.510	65.507
b, g	-21.938	.264	-19.303	-22.200	-19.782	-18.581	-21.647	-23.241
r	.981	3.896E-4	.987	.985	.981	.991	.981	.979
R_{adj}^2	.919		.985	.987	.951	.967	.948	.943
σ^2	2.036		.266	.362	.965	.818	1.274	1.506

* excluded from the overall fit

Table 4 shows the results for the floor eggs. The results in Table 4 show that the initial percentage of floor eggs varies between 3.2 and 18.7%. The coefficients of determination per flock are between .7 and .9, which means that the chosen mathematical curve describes the percentage of floor eggs reasonably well. The overall fit, however, shows a very poor coefficient of determination. This means that each flock has his own curve that describes the percentage of floor eggs. There is a lot of daily variation within and between flocks.

Table 4 Parameter fits for floor eggs (%) for six separate aviary flocks and the overall fit with their asymptotic standard error (ase).

$$Y_{floor\_eggs} = a * e^{-b*t} + c * t + d * t^2$$

Parameters	Overall fit		Flock number					
		ase	1	2	3	4*	5	6
a, %	9.390	.391	3.183	4.449	9.329	21.678	12.852	18.672
b, %/d	.025	1.709E-3	-4.185E-3	.029	2.863E-2	1.967E-2	4.075E-2	2.190E-2
c, %/d	3.187E-2	1.374E-3	-7.928E-3	7.682E-3	2.364E-2	4.546E-2	4.304E-2	5.905E-2
d, %/d²	-5.573E-5	4.511E-6	-7.485E-5	-9.020E-6	-2.479E-5	-1.155E-4	-7.440E-5	-1.100E-4
R_{adj}^2	.106		.826	.843	.806	.903	.716	.809
σ^2	6.598		.068	.058	.276	1.748	.796	.955

* excluded from the overall fit

Table 5 Parameter fits for second grade eggs (%) for four aviary flocks and for the overall fit with their asymptotic standard error (ase).

$$Y_{second\_grade\_eggs} = a + b * t + c * t^2$$

Parameters	Overall fit		Flock number			
		ase	1	2	3	4*
a, %	4.527	.242	6.455	2.985	4.314	10.360
b, %/d	-.027	.003	-.034	-.016	-.032	-.074
c, %/d^2	1.056E-4	7.351E-6	1.261E-4	4.396E-5	1.507E-4	1.775E-4
R_{adj}^2	.337		.462	.533	.873	.376
σ^2	7.077		5.077	.205	1.594	7.036

* excluded from the overall fit

Data to fit the parameters for the mathematical curve that describes the percentage of second grade eggs were present from four flocks. The results are shown in Table 5. As with the percentage of floor eggs, the initial percentage of second grade eggs differs a lot between flocks. The coefficients of determination per flock ranges from .4 to .9. This implies that the chosen mathematical curve is better than using the mean, but that it is difficult to give just one mathematical curve that can be used for all flocks. Daily variation within flocks shows also a broad range from .2 to 5.1.

The parameter fits for the feed and water consumption mathematical curves are shown in Table 6. The coefficients of determination for feed consumption vary between .5 and .7 and for water consumption they vary between .5 and .8. The overall fits for feed consumption and water consumption, respectively, are .4 and .5. Per flock the mathematical curves differs, so it is difficult to give just one overall fit for the feed and water consumption. Variance for the feed consumption is between 10.5 and 34.8 per flock, whereas the overall variance for the feed consumption is 37.4. This means that besides the variation between flocks there is also a lot of daily variation within a flock. The same can be seen for the water consumption, although there is relatively more variation between flocks.

For the statistical analysis of the body weight and flock uniformity only two data sets are present. From Flock 6 also data from the first 85 d are missing, which makes it difficult to fit the data well. The parameter fits for body weight and flock uniformity are shown in Tables 7 and 8, respectively.

Table 6 Parameter fits for feed consumption (g) and water consumption (cl) for five separate aviary flocks and for the overall fit with their asymptotic standard error (ase).

$$Y_{feed\_or\_water} = \frac{a}{1 + b * e^{-a * c * t}} + d * t + e * t^2$$

Feed consumption Parameters	Overall fit		Flock number				
		ase	2	3	4*	5	6
a, g	121.513	1.434	127.844	128.938	104.942	116.064	111.905
b	.434	.022	.633	.390	.259	.431	.390
c, $(g.d)^{-1}$	4.027E-4	3.653E-5	2.894E-4	4.394E-4	9.101E-4	5.903E-4	6.499E-4
d, g/d	-.028	.013	-.022	-.137	-3.767E-2	3.833E-4	5.861E-2
e, g/d^2	1.617E-5	2.768E-5	1.625E-6	2.494E-4	1.054E-4	-3.726E-5	-1.789E-4
R_{adj}^2	.422		.677	.584	.089	.693	.538
σ^2	37.435		34.804	11.473	59.812	10.472	27.116

Water consumption Parameters	Overall fit		Flock number				
		ase	2	3	4*	5	6
a, cl	227.126	1.675	234.295	223.626	228.093	228.651	233.882
b	.854	.058	.780	.467	.407	1.065	1.242
c, $(cl.d)^{-1}$	5.480E-4	4.172E-5	3.876E-4	9.441E-4	1.446E-4	5.549E-4	4.112E-4
d, cl/d	.180	.018	-1.053E-2	.202	-.113	.218	.198
e, cl/d^2	-5.418E-4	4.225E-5	9.639E-5	-4.481E-4	2.260E-5	-8.057E-4	-7.791E-4
R_{adj}^2	.543		.765	.496	.644	.769	.814
σ^2	192.983		69.289	101.182	56.521	114.267	119.053

* excluded from the overall fit

The coefficients of determination per flock and for the overall flock are good. The lower coefficient of determination for Flock 6 can be explained by the missing data at the begin of the laying period. The coefficients of variation differ a lot between the two flocks, which means that the curves have a different form. The low coefficient of variation of Flock 6 probably is caused by a lot of missing data.

Table 7 Parameter fits for body weight (g) for aviary flocks and the overall fit with their asymptotic standard error (ase)

$$Y_{body\_weight} = \frac{a}{1 + b * e^{-a * c * t}} + d * t$$

Parameters	Overall fit		Flock number	
		ase	5	6
a, g	1722.439	3.952	1717.037	1727.881
b	.175	.012	.170	2.389
c, $(g.d)^{-1}$	1.52 E-5	1.25 E-6	1.57E-5	1.64E-4
d, g/d	.390	.013	.392	.389
R_{adj}^2	.919		.933	.798
σ^2	346.503		348.323	264.400

The parameter values for the mathematical curve that describes the cumulative mortality are given in Table 9. Cumulative mortality in Flock 4 showed much more variation than the other flocks, which probably was related to the aberration in the production process.

Table 8 Parameter fits for flock uniformity (%) for two aviary flocks and for the overall fit with their asymptotic standard error (ase).

$$Y_{flock\_uniformity} = a + b * t + c * t^2$$

Parameters	Overall fit		Flock number	
		ase	5	6
a, %	58.563	.557	58.883	53.615
b, %/d	.113	5.447E-3	.121	.141
c, $\%/d^2$	-2.550E-4	1.176E-5	-2.728E-4	-2.983E-4
R_{adj}^2	.420		.614	.327
σ^2	10.782		6.065	14.828

Table 9 Parameter fits of the cumulative mortality (%) for six separate aviary flocks and the overall fit with their standard error (se)

$$Y_{cumulative\_mortality} = a * t + b * t^2$$

Parameters	Overall fit		Flock number					
		se	1	2	3	4*	5	6
a, %/d	7.563E-3	3.080E-4	6.732E-3	.018	9.519E-3	8.507E-4	2.483E-3	1.205E-3
b, %/d^2	6.183E-6	1.042E-6	-5.394E-6	-1.412E-5	8.608E-6	2.971E-5	1.876E-5	2.306E-5
R_{adj}^2	.675		.943	.978	.999	.885	.991	.977
σ^2	.549		.012	.042	2.968E-3	.225	.011	.028

* excluded from the overall fit

The coefficients of determination per flock are greater than .9 which means that the chosen mathematical curve fits well to the data of the separate flocks. The coefficient of determination for the overall fit is somewhat lower, which means that there are differences between flocks. Variance of the overall fit is also much higher than the variance within flocks, which means there are large difference between flocks.

The mean and the standard deviations of the ambient temperatures of the six flocks are shown in Table 10. The mean ambient temperature varies between 21.36 and 23.02 C, and the standard deviation between 1.13 and 2.31. Thus, within flocks there is more daily variation than between flocks.

Table 10. Mean and standard deviation (sd) ambient temperature (°C) for six flocks that are housed in an aviary system.

	Flock number					
	1	2	3	4	5	6
mean	21.36	22.98	22.82	21.86	22.96	23.02
sd	2.096	1.752	1.542	2.312	1.125	1.188

Table 11 summarizes the overall fitting results of the mathematical curves. Besides the coefficients of variation are given with the expected means. The coefficient of variations give information on the daily variations, relative to their means, of the production variables.

Table 11. Overall coefficients of determination ($R_{adj}{}^2$) and standard deviation (sd) and minimum and maximum coefficients of determination, standard deviations, coefficients of variation (CV) and expected means (μ) per flock for the mathematical curves

	Overall		Per flock						
	R_{adj}^2	sd	R_{adj}^2 min	R_{adj}^2 max	sd min	sd max	μ	CV min (%)	CV max (%)
INPUT									
feed consumption (g)	.42	6.12	.54	.69	3.24	5.90	115	2.8	5.2
water consumption (cl)	.54	13.89	.50	.81	8.32	10.91	230	3.6	4.8
ambient temperature (C)					1.13	2.31	23	4.9	10.6
OUTPUT									
cumulative mortality (%)	.68	.74	.94	1.00	.05	.20	3	1.7	6.7
hen-day egg production (%)	.87	4.90	.91	.99	1.62	3.41	85	1.9	4.0
egg weight (g)	.92	1.43	.94	.99	.52	1.23	62	.8	2.0
body weight (g)	.92	18.61	.80	.93	16.26	18.66	1700	1.0	1.1
flock uniformity (%)	.42	3.28	.33	.61	2.46	3.85	68	3.6	5.7
second grade eggs (%)	.34	2.66	.46	.87	.45	2.25	5	9.1	45.1
floor eggs (%)	.11	2.57	.72	.84	.24	.98	5	4.8	19.5

4. DISCUSSION

4.1. *Mathematical Curves*

The suggested mathematical curves for the description of the daily production process are better than just using mean values of the production variables, but they are not all equally successful in describing the daily production of laying hens in an aviary system.

The minimum and maximum values of the coefficients of determination per flock of the mathematical curves for the cumulative mortality, hen-day egg production, egg weight, body weight and percentage of floor eggs vary between .72 and 1.00 (Table 11). This implies that these mathematical curves fit the individual flocks very well. The coefficients of determination of the overall fits for the hen-day egg production, egg weight, and body

Stellingen

1. Door uit te gaan van de kritische succesfactoren: voeropname, staltemperatuur en tijdige opsporing van ziektes en door gebruik te maken van dagelijkse in plaats van wekelijkse produktiegegevens beschikt de pluimveehouder over de belangrijkste middelen om het produktieproces in volièrestallen voor leghennen te beheersen.
Dit proefschrift

2. Het ter beschikking hebben van (geautomatiseerde) monitoringsystemen stelt de pluimveehouder in staat beter te voldoen aan het algemeen geldende voorschrift om dagelijks zijn kippen te inspecteren.
Dit proefschrift; Beschikking legbatterijen

3. Voor het beoordelen van de gebruiksmogelijkheden van geautomatiseerde dierweegsystemen voor pluimvee is het gebruik van individuele dierherkenning met behulp van transponders voorwaarde.
Dit proefschrift

4. Land- en tuinbouwbedrijven zijn dermate afhankelijk geworden van nutsbedrijven dat aangeraden moet worden om eigen noodvoorzieningen te treffen.

5. Veel eerder dan economische zullen politieke keuzes ervoor moeten zorgen dat het marktaandeel van produkten die geproduceerd zijn in welzijnsvriendelijke huisvestingssystemen toeneemt.

6. Het succes van op techniek gebaseerde oplossingen in de huisvesting en houderij ter bevordering van het welzijn van landbouwhuisdieren wordt in toenemende mate bepaald door het aanpassingsvermogen van deze dieren.

7. Omdat mensen onvoldoende in staat zijn om niet lineaire processen te doorzien worden neurale netwerken met voordeel toegepast bij de beheersing van produktieprocessen in de land- en tuinbouw.

8. Vele, op ad hoc beleid gebaseerde milieu- en welzijnsmaatregelen zijn onvoldoende getoetst op hun gevolgen voor mens en dier.

9. '... in real life mistakes are likely to be irrevocable. Computer simulation, however, makes it economical practical to make mistakes on purpose. If you are astute, therefore, you can learn much more than they cost. Furthermore, if you are at all discreet, no one but you need know you made a mistake.'
H.H. Pattee et al., 1966. Natural automata and usefull simulations, McMillan, London

10. Een duurzame landbouw vereist managers met een (informatie)technologisch hart en een ecologische ziel.

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31 Mei 1996, Wageningen.

weight are also high, which means that there is not much variation between flocks. This can also be seen in Figure 1 and 2. The implication is, that these mathematical curves may give reasonable estimations for the parameters of other flocks too. But, it is always possible to do a fine tuning, by regularly fitting the curves with the collected data, during the laying period. The general curves are then adjusted to the specific flock circumstances.

The low overall coefficients of determination for the cumulative mortality and the percentage of floor eggs implies that there is a lot of variation between flocks. This makes it difficult to estimate the parameters of these mathematical curves in advance. Once a flock has started the laying period, the parameters can be adjusted to the flock specific situation. From then on it is expected that the parameters give a reasonable fit for a specific flock.

The coefficients of determination per flock for the mathematical curves that describe the feed consumption, water consumption, flock uniformity and the percentage of second grade eggs are in general low (Table 11). Within a flock there is a lot of daily variation, which influences the coefficients of determination. This can partly be explained by the fact that the poultry farmers influences the input variables feed and water consumption. Based on the results of the output variables of the production process he actively influences the input variables. Naturally the coefficients of determination for the overall fits of these mathematical curves are also low. Especially the curves of the feed and water consumption show different curve forms between flocks (Figure 1,2). This leads to the conclusion that it is very difficult to estimate the parameters for these mathematical curves for other flocks. Once a flock has started the laying period the estimation parameters can become better, but the mathematical curve should be fitted during the laying period regularly to the data.

Mathematical curves can be used in monitoring the production process. The mathematical curves can act as a reference value for the real production results. From our analysis it becomes clear that if the mathematical curves are used as reference value they must be fitted more or less regularly to the flock specific circumstances. The predicted values then are closest to the real production results. The parameter fits presented in this paper can serve as a good starting point for a proper setting of the parameters.

4.2 *Normal Daily Process Variation*

In order to detect aberrations or exceptional process variation in the production process, it is important to know the normal production variation (Deming, 1986). According to the minimum coefficients of variation of the flocks, the production variables can be separated into three classes. The first class with minimum coefficients of variation between .8 and 1.9 (Table 11) consists of egg weight, body weight, cumulative mortality, and hen-day egg production. These variables have also the lowest maximum coefficients of variation (1.1 to 4.0), except for the cumulative mortality. The second class with a minimum coefficient of variation between 2.8 and 3.6 and a maximum coefficient of variation between 4.8 and 5.7, consists of the variables feed consumption, water consumption and flock uniformity. The third class with minimum coefficients of variation between 4.8 and 9.1 and maximum coefficients of variation between 10.6 and 45.1, consists of the variables ambient temperature, percentage floor eggs, and percentage of second grade eggs.

It can be concluded from the results of Table 11 that the daily percentages of second and floor eggs show so much variation, that they are difficult to use as management parameters to monitor the daily production process. The ambient temperature shows also a lot of variation between days (4.9 to 10.6), which was not expected because the temperature was controlled by climate computers. This daily variation in ambient temperature has its effect on the daily feed and water consumption. According to Luiting (1990) 54% of the gross energy consumption is used for the heat production loss, which consists of heat production for maintenance and heat increment of production. The daily variation in feed and water consumption is between 2.8 and 5.2. So, most of the variation in the daily variation of the ambient temperature is compensated by the daily variation in feed and water consumption. Another part of the daily variation in ambient temperature has its effect on the egg production (hen-day egg production between 1.9 and 4.0 and egg weight between .8 and 2.0) and body weight gain. The mean daily body weight shows less variation (1.0 to 1.1) than the flock uniformity (3.6 to 5.7). Probably, competition on the feed and water has its effect on the flock uniformity.

To monitor the daily production process in an aviary system for laying hens the poultry farmer primarily should look at the ambient temperature, feed consumption, water consumption, hen-day egg production, egg weight, body weight and flock uniformity. Cumulative mortality can also be used to monitor the daily production process. To control the production process it is important that the poultry farmer tries to reduce the daily variation in the ambient temperature. By concentrating on exceptional variation and not looking at normal process variation the poultry farmer can control better the three CSF on feed consumption, ambient temperature and the timely detection of diseases.

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Chapter 7

An expert system for monitoring the daily production process in aviary systems for laying hens

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An expert system for monitoring the daily production process in aviary systems for laying hens

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Abstract

An expert system (ES) for monitoring aberrations related to feed consumption, ambient temperature and disease detection was developed in order to support day-to-day management on aviary farms for laying hens. Knowledge of 5 experts was stored in the knowledge base, which consisted of aberration tables for standardising the knowledge representation and inference mechanism of the ES. Detection of aberrations in the production process is based on quantitative and qualitative data. According to the experts, the important quantitative data are: feed consumption, water consumption, ambient temperature, hen-day egg production, egg weight, body weight, flock-uniformity, second grade eggs, floor eggs and mortality. Data from four flocks and five standards were used for the sensitivity analysis and to validate the ES. The sensitivity analysis and the validation showed the importance of choosing a good standard and detection limit. Using farm-specific mathematical curves as standard and a practical set of detection limits, the sensitivity of the ES was 64 % and the specificity was 72 %. Using a set of starting detection limits, the sensitivity was 91 %, but specificity then declined to 28 %.

1. Introduction

Changes in consumers' attitudes towards poultry production systems for laying hens in Western Europe have resulted in an increasing demand for humanely produced eggs. Aviary housing systems have been developed as a potentially economically viable alternative to cage systems, to benefit the welfare of laying hens (Blokhuis and Metz, 1995). For descriptions of prototypes of aviary systems, see Ehlhardt *et al.* (1988), Appleby *et al.* (1992) and Blokhuis and Metz (1995).

Professional daily management in aviary systems must focus on monitoring and controlling three main critical success factors (CSF): feed consumption, disease detection and control of the ambient temperature (Lokhorst *et al.*, 1996). Monitoring or tracing deviations in the daily production process involves three major aspects: 1) measuring the flock performance, 2) establishing standards, and 3) comparing flock performance with standards (Huirne, 1990). Daily flock performance is established by various variables. Some of them (e.g. ambient temperature, number of eggs, hen-day egg production, feed consumption and egg weight) are quantitative, others (e.g. the colour of the faeces, the noise made by the hens, and the colour of the comb) are qualitative (Lokhorst et al., 1996). The choice of an appropriate standard depends on the specific monitoring situation and its variation (Kay, 1986; Huirne, 1990; Hennen, 1995). Deming (1986) distinguishes two sources of variation, 1) normal process variation and 2) exceptional process variation. Normal process variation is inherent to the system, permanently present and its influence on the production process is relatively small and unpredictable. It cannot be assigned to one specific cause. Exceptional process variation has an external cause, is incidental (one at a time), local and it has a large influence on the production process. So, detection of aberrations in the production process must be aimed at the detection of exceptional process variation in the daily flock data.

Monitoring could be performed by the poultry farmer himself, but it is time consuming and complex. In poultry production systems it is, however, possible to record many quantitative production data automatically using process computers, and to store these data in a management information system (Belyavin,1988; ATC,1994). Furthermore it might be useful to exploit the potential of computers and to develop an expert system (ES). This implies assembling the knowledge of experts in monitoring the daily production process and tracing aberrations in that production process, and transforming all this information into a computer program which can be used by different people, including those who would otherwise not have the management skills to perform the daily analysis.

Existing ES for poultry production systems (Schmisseur and Pankratz, 1989; Goedeke, 1989) do not focus on the monitoring of the daily production process, but are related to longer periods. Day-to-day management in aviary housing systems needs to be supported, and therefore the aim of this study was to develop and validate an ES that supports the monitoring of the day-to-day feed consumption, disease detection and ambient temperature in aviary systems for laying hens.

2. Materials and methods

2.1 Animals and data collection

Daily data from four flocks of white LSL hens were used to determine appropriate detection limits and to validate the ES (see Table 1). Flocks 1 and 2 were housed in two aviary housing systems on a commercial poultry farm. Flocks 3 and 4 were housed in two aviary systems on the 'Spelderholt' experimental farm.

Data on mortality, numbers of first grade and floor eggs were recorded for all flocks. The daily mean egg weight was determined by weighing the first pile of six egg-trays per flock with a total of 180 eggs (Lokhorst and Keen, 1995). Daily consumption of feed and water, and minimum and maximum temperatures, both inside and outside the houses, were registered automatically by process computers. Mean body weight and the variation in mean body weight that is expressed as flock-uniformity were registered daily by an automatic weighing system. For this, four weighing scales were placed in the middle of the upper feed tiers in each flock (Lokhorst, 1996a). The number of second grade eggs was recorded for flocks 3 and 4.

The manually and automatically registered data were stored in GACLEG, a commercial management information system for poultry production. This system is unable to present daily data and index figures. Therefore, LayVision, a prototype for a decision support system (DSS) that helps farmers to analyse the data recorded daily, was developed to provide a user friendly environment to connect the actual production results, a standard and the ES. The development and the characteristics of the ES part of LayVision are described in this paper. In LayVision the flock data are compared with a standard and the percentage of deviation from the standard of each relevant variable is input for the ES. Table 2 shows an example of the input for the ES.

Table 1. Data collection and details on flocks involved

Flock no.	Size	Duration of data collection (days)	Age (days) of hens during data collection	
			at start	at end
1	15 956	325	200	525
2	15 900	164	305	525
3	1 000	177	141	318
4	1 000	177	141	318

2.2. Standards

Five standards were tested (Table 3) to ascertain their suitability for use in the ES. The first standard which is used frequently on commercial poultry farms, is from the LSL breeding company, and consists of weekly data on hen-day egg production, feed consumption and egg weight. To overcome the problem that only three variables are present in the standard and that the standard is based on weekly data the second and third standards consist of mathematical curves (Lokhorst, 1996b), each representing one of the following input or output variables of the production process as a function of age: feed consumption, water consumption, hen-day egg production, egg weight, second grade eggs, floor eggs, cumulative mortality, body weight and flock-uniformity. The ambient temperature in these two standards is set at 23 °C. Standard 2 is based on an average of daily data from 6 aviary flocks and standard 3 consists of flock- specific mathematical curves, which are fitted separately for each flock (Lokhorst, 1996b). The fourth and fifth standards are short-term predictions that are based on moving averages of the actual flock data for respectively three (MA3) and seven days (MA7). Moving averages were calculated daily for the hen-day egg production, mean egg weight, percentage of second grade eggs, percentage of floor eggs, feed consumption, water consumption, mean body weight, flock uniformity, cumulative mortality and the ambient temperature.

2.3. Knowledge acquisition

In this research, interviews with five experts and literature were the main source of knowledge. Knowledge was acquired in three steps. The first step defines the domain area by using general information from an expert. Our main expert, an advisor with more than 30 years of practical experience, was interviewed to obtain information on the domain area. Topics related to the production process, such as feed consumption and digestibility, water consumption, illumination, flock uniformity, body weight and climate, were discussed.

Table 2. Example of the input of day number 442 of flock 1 for the ES.

Comparison of :	**Flock 1** with	**Overall curves**	
Age: 442 Days Date: 19-08-1993			
Variables	**Data**	**Standard**	**Deviation (%)**
NUMBER OF HENS	15 523		
Cumulative MORTALITY (%)	2.6	2.8	-0.2
FEED/HEN/DAY (g)	110.8	112.4	-1.4
WATER/HEN/DAY (cl)	217.2	223.4	-2.8
HEN-DAY EGG PRODUCTION (%)	81.9	81.2	0.7
SECOND GRADE EGGS (%)	0.0	5.6	-5.6
FLOOR EGGS (%)	6.0	4.1	1.9
EGG WEIGHT (g)	65.1	65.1	0.0
BODY WEIGHT (g)	1 843	1 840	0.2
FLOCK-UNIFORMITY (%)	70.3	75.0	-4.7
AMBIENT TEMPERATURE (°C)	24.1	23.0	4.8

The second step was to define aberrations, select qualitative and quantitative variables, and estimate the magnitude of the quantitative variables. The results of the interviews in step one and of a study of the literature on poultry diseases (Devos, 1971; Voeten, 1987; Sainsbury, 1992) were used to draw up a list of relevant aberrations in the production process. The quantitative and qualitative variables that deviate from the standard were also listed per standard, giving the estimated magnitude and sign (+ or -) of the former.

Table 3. Characteristics of standards tested for their usefulness in the ES component of LayVision

standard no.	name	based on		flock-specific		number of variables (max = 10)
		weekly data	daily data	no	yes	
1	LSL standard	x		x		3
2	Overall curves		x	x		10
3	Flock-specific curves		x		x	10
4	Extrapolation (MA3)		x		x	10
5	Extrapolation (MA7)		x		x	10

In the third step four other experts were consulted, to check the ideas of the main expert. The list of aberrations with their variables was checked independently by the four other experts, who were asked to check for completeness and correctness. They were also asked independently to estimate the magnitudes and signs of the deviations from the standards and to estimate the contribution of each variable to the certainty that that aberration would occur. The results obtained from the four experts were discussed again with the main expert. This resulted in the final list of aberrations with quantitative and qualitative variables, their sign and magnitude and their degree of certainty. This information was then stored in the knowledge base of the ES.

2.4 Knowledge representation and inference mechanism

The knowledge representation and inference mechanism of the ES, by which the knowledge can be retrieved from the system, were standardised in aberration tables. The whole ES has been built up from 12 aberration tables. Each day the real flock data are checked, according to a special procedure, with the knowledge stored in the aberration tables. The inference mechanism consists of six steps, which are explained below, using one aberration table as an example. Table 4 shows the example of the aberration table "respiratory disorder" .

In step one the deviations between the flock results and the standard of all quantitative variables (table 2) are compared with the deviations of the relevant quantitative variables of the aberration table. General symptoms of a respiratory disease are rattling respiration, a dry cough, wheezing, screeching, or gaping. It is difficult to measure these symptoms. In the case of a respiratory disorder, the experts also expected that feed consumption, water consumption and hen-day egg production would decline, and that the percentage of floor eggs and second grade eggs would increase. They divided the severity of the deviation into starting, advanced and serious: if the deviation of the water consumption was between -2 and -5 % the deviation was classified as starting, if it was more than a 9 % decrease in the water consumption the deviation was classified as serious. A Variable Assessment Factor (VAF) was coupled to each combination of a quantitative variable and the severeness (starting, advanced, serious). The VAF is a number between 0 and 10, with 0 indicating no effect on the aberration and 10 a very large effect of the deviation of the quantitative variable on the aberration. To decide if an aberration is present, the VAF values of the quantitative variables are combined to one Variable Certainty Factor (VCF). The VCF for an aberration table is calculated with the formula:

```
$VCF_0 = 0$
FOR i FROM 1 TO maxvar DO
    $VCF_i = VCF_{i-1} + (1 - VCF_{i-1}) * \frac{VAF_i}{10}$
LOOP
$VCF = 10 * VCF_{maxvar}$
```

in which i is the number of the variable in the aberration table and maxvar is the number of variables in that table. The maxvar for the respiratory disorder example is 5. If all the variables have a deviation classified in the starting category the VCF becomes 5.3. The

Table 4. Example of the aberration table for a respiratory disorder (VCF = Variable Certainty Factor; VAF = Variable Assessment Factor; QCF = Question Certainty Factor, QAF = Question Assessment Factor).

<table>
<tr><td colspan="7">Aberration table: Respiratory disorder</td></tr>
<tr><td colspan="7">Step 1: Compare deviations and calculate the VCF</td></tr>
<tr><td rowspan="2">Variables (I)</td><td colspan="2">Starting</td><td colspan="2">Advanced</td><td colspan="2">Serious</td></tr>
<tr><td>Dev. (%)</td><td>VAF_I</td><td>Dev.(%)</td><td>VAF_I</td><td>Dev. (%)</td><td>VAF_I</td></tr>
<tr><td>1. water cons. (cl/hen.day)</td><td>- 2</td><td>1</td><td>- 5</td><td>5</td><td>- 9</td><td>8</td></tr>
<tr><td>2. floor eggs (%)</td><td>2</td><td>2</td><td>4</td><td>5</td><td>10</td><td>7</td></tr>
<tr><td>3. hen-day egg product. (%)</td><td>-1</td><td>1</td><td>- 4</td><td>4</td><td>- 9</td><td>6</td></tr>
<tr><td>4. feed cons. (g/hen.day)</td><td>-2</td><td>1</td><td>- 5</td><td>3</td><td>- 12</td><td>5</td></tr>
<tr><td>5. second grade eggs (%)</td><td>5</td><td>2</td><td>11</td><td>4</td><td>20</td><td>5</td></tr>
<tr><td colspan="4">Step 2: If (VCF > detection limit) then present aberration and put general questions</td><td colspan="3">Detection limit = 6</td></tr>
<tr><td colspan="7">Step 3: Update VCF with general questions</td></tr>
<tr><td colspan="6">General questions</td><td>VAF</td></tr>
<tr><td></td><td colspan="5">Are the hens gasping ?</td><td>8</td></tr>
<tr><td></td><td colspan="5">Are they making unusual noises ?</td><td>8</td></tr>
<tr><td colspan="4">Step 4: If (VCF > detection limit) then specific questions</td><td colspan="3">Detection limit = 7</td></tr>
<tr><td colspan="7">Step 5: Calculate the QCF_{sub_aber} per sub-aberration</td></tr>
<tr><td>Sub-aberrations: (sub_aber)</td><td colspan="3">1 NCD
2 IB
3 ILT
4 CRD</td><td colspan="3">5 Swollen Head Syndrome
6 Acute Coryza
7 Fowl pox/Diphtheria</td></tr>
<tr><td colspan="6">Specific questions (sq)</td><td>QAF_{sq}</td></tr>
<tr><td>re 1</td><td colspan="5">Are the hens twisting their necks ?</td><td>10</td></tr>
<tr><td>re 7</td><td colspan="5">Smallpox on the comb, diphtheria in the mouth ?</td><td>10</td></tr>
<tr><td>re 4 5 6</td><td colspan="5">Discharge from the nostrils ?</td><td>8</td></tr>
<tr><td>re 3</td><td colspan="5">Discharge of blood from nose and mouth ?</td><td>8</td></tr>
<tr><td>re 1 2</td><td colspan="5">Sandy and misshapen eggs ?</td><td>7</td></tr>
<tr><td>re 2</td><td colspan="5">Abnormally coloured eggs ?</td><td>7</td></tr>
<tr><td>re 5</td><td colspan="5">Inflammation and liquid accumulation on the head ?</td><td>7</td></tr>
<tr><td>re 1</td><td colspan="5">Green faeces ?</td><td>6</td></tr>
<tr><td>re 1 2 3 5</td><td colspan="5">Irritated eyes ?</td><td>6</td></tr>
<tr><td colspan="7">Step 6. Show sub-aberrations with a $QCF_{sub\_aber} > 0$</td></tr>
</table>

variables in the aberration table are ranked according to their VAF for the classification "serious".

To reduce the number of questions the farmer is asked daily, in step two a detection limit is incorporated in the inference mechanism. If the VCF exceeds a detection limit, the poultry farmer receives a warning that an aberration might be present. This warning is based solely on the analysis of the quantitative data. In step three the poultry farmer has the option for a further analysis by answering questions concerning qualitative data. General questions can improve the VCF, and thus the certainty of that aberration, if questions are answered affirmatively. Each aberration table has its own general questions.

If, after the general questions, a second detection limit is exceeded, the poultry farmer can further diagnose the problem (step four). Based on specific questions the ES gives possible causes, the sub-aberrations (step five), of the aberration. The sub-aberrations are numbered in the aberration table. Newcastle Disease (NCD), Infectious Bronchitis (IB), Infectious Laryngotracheitis (ILT), Mycoplasma infection (CRD), Swollen Head Syndrome, Acute Coryza and Fowl pox are the sub-aberrations of the aberration "respiratory disorder". Each specific question can be answered "yes" or "no". In the case of "yes", the QAF factor is used to calculate the question certainty factor ($QCF_{sub\text{-}aber}$), which is calculated with the following formula:

```
FOR sub_aber FROM 1 TO max_sub_aber DO
    $QCF_{sub\_aber} = 0$
    FOR sq FROM 1 TO maxques DO
        $QCF_{sq} = QCF_{sq-1} + (1 - QCF_{sq-1}) * \frac{QAF_{sq}}{10}$
    LOOP
    $QCF_{sub\_aber} = 10 * QCF_{maxques}$
LOOP
```

Each question is linked with one or more symptoms of one or more sub-aberrations. The questions are linked to the sub-aberrations by a number. For example, hens with NCD are characterized by twisted necks, sandy and misshapen eggs, green faeces and irritated eyes. As with the variables, it is not necessary for all questions relating to a sub-aberration to be answered affirmatively. All sub-aberrations with a QCF greater than zero are displayed on screen (step six).

2.5 Standards and detection limits

An analysis was performed to ascertain the applicability of standards and detection limits, and the sensitivity of the expected deviations, estimated by the experts, was studied.

Using data from the four flocks and five standards (table 3), the daily VCFs were calculated. Per standard, the VCFs of the four flocks were averaged and the 75 % (P75), 90 % (P90) and 95 % (P95) percentiles were determined. A P95 percentile gives the value for the VCF for which 95 % of the days the VCF for that specific aberration is lower than the P95 percentile. The results of these percentiles were compared with three different sets of detection limits. The first set of detection limits is based on a theoretical starting aberration. If deviations of all variables per aberration are classified as starting, the VCF can be calculated. For the respiratory disorder the detection limit is then calculated as 5.3. The second set of detection limits is based on the classifications of advanced deviations. In this case the detection limit for the respiratory disease is calculated as 9.4. The third set of detection limits is based on graphs of the daily VCF per aberration and was set by us. The basic function of using a detection limit is to reduce unnecessary warnings or false positive warnings. Aberrations with a VCF below the detection limit are not displayed to the poultry farmer. Comparing the calculated VCFs per standard and the three sets of detection limits reveals how many days the poultry farmer will be confronted with a warning that a certain aberration is present.

To determine the value of the deviations estimated by the experts and stored in the aberration tables, these estimations were compared with the expected daily variation. Lokhorst (1996b) analysed six flocks of laying hens that were housed in aviary systems. Results of the minimum and maximum daily variation per quantitative variable, expressed as the coefficients of variation, found in those flocks were compared with the minimum and maximum estimated starting, advanced and serious deviations. If the deviation for a certain variable estimated by the expert is lower than the minimum coefficient of variation, it can be expected that many false warnings will follow, because one is searching within the normal daily variation. However, the ES aims at finding exceptional process variation in the production process, which implies that the ES searches for deviations per variable that are larger than the normal daily variation.

2.6 Validation

Validation can be described as the comparison between the ES computer system and the observed world (Gilchrist, 1984). The validation process can be separated into an internal validation and an external validation (Taylor, 1983). The internal validation ensures the developers that the right answers, decisions or recommendations are provided by the correct method, and that each part of the ES has a logical basis, uses the correct parameters and is correctly programmed. The external validation reveals the capability of the ES to detect real observed and expected errors.

The internal validation was performed by confronting the five experts with the aberration tables. Each aberration table covers a specific aberration and all information needed is presented in a standardised way. This made it easy for the experts to check for completeness.

Table 5. Aberrations in four flocks registered by the poultry farmer.

Flock no.	Age (days)	Aberration
1	233	Worm infection
	296	Reaction to medication for worm infection
	442	Water distribution error of one day
2	420	Water distribution error of 1.5 day
3	153	Drinking nipple leaks
	184	Drinking nipple leaks
	264	Feed distribution error
4	178	Drinking nipple leaks
	268	Water distribution error
	295	Feed distribution error
	305	Water distribution error

In the external validation the sensitivity and the specificity of the ES were determined for combinations of the five standards described (Table 3) and the three detection limits described. The sensitivity is the percentage of the total number of aberrations according to the poultry farmers correctly signalled by the ES. The specificity is the aberrations not detected by the ES expressed as a percentage of the total number of days that no aberration was present according the poultry farmers. The poultry farmers of the four flocks were asked to record the date and causes of abnormal production circumstances. The annotated aberrations are shown in Table 5. The water distribution errors in flock 4 at the age of 268 days and at the age of 305 days were deliberately induced. For each water distribution error the water supply was shut off for approximately 12 hours.

The sensitivity and the specificity of the ES were determined to detect the aberrations that were mentioned by the poultry farmers. In order to relate sensitivity and specificity to the standard and the detection limits that could be used, they were determined for the combinations of the five standards (Table 3) and the three detection limits (starting, advanced and practical).

3. **Results**

3.1 Aberrations

The experts classified 39 sub-aberrations which could be distributed over 12 aberrations within the critical success factor areas of feed consumption control, ambient temperature control and early disease detection (Table 6). Table 6 shows the names of the aberration tables and the quantitative variables that deviate from their standard if an aberration occurs.

Table 6 indicates that the experts needed the quantitative variables feed consumption, water consumption, hen-day egg production, percentage of second grade eggs, percentage of floor eggs, egg weight, body weight, cumulative mortality, flock-uniformity and ambient temperature to find aberrations concerning the CSF in aviary housing systems. They estimated that more than 80 % of all possible diseases and more than 90 % of other aberrations could be detected with the ES. Table 6 shows that most quantitative variables are influenced by more than one aberration. For example, feed consumption is correlated with 9 aberrations, water consumption with 8, hen-day egg production and egg weight each with 6. However, the sign and the magnitude of a quantitative variable differs between aberrations. A feed consumption higher than the expected standard can be seen for the aberration 'Extremely cold day', while the feed consumption for the other 8 aberrations is lower than the standard.

3.2 Standards and detection limits

The results of the VCF for the 12 aberrations and the five standards and for the three detection limits are summarised in table 7. No VCF could be calculated for standard 1 in combination with the aberrations 'High and fast mortality' and ' Disturbance in the water installation', because the relevant quantitative variables were not present in that standard. The value of 9.0 in the P95 standard 5 cell for the respiratory disorder must be interpreted as follows: when the Extrapolation (MA7) standard was used, on five percent of the monitored days a VCF of more than 9.0 occurred for the respiratory disorder. If the number of warnings was not allowed to be so high a very high detection limit was needed when the extrapolation (MA7) was used as standard. The theoretical detection limit is the VCF calculated if all quantitative variables of an aberration table fall in the starting category. If these detection limits are used, many false warnings will occur - more than 25 % for a respiratory disorder if the overall curves are used as standard, between 25 % and 10 % if the specific curves and the extrapolations (MA3 and MA7) are used, and less than 5 % if the LSL standard is used. The results in table 7 show that the VCFs of the LSL standard are lower than the VCFs of the other standards. This can be explained by the number of quantitative variables that are encountered in the standards.

Table 6. Aberrations per Critical Success Factor and their related quantitative variables (+ = actual data higher than standard is correlated with aberration, - = actual value of data lower than standard is correlated with aberration).

	Quantitative variables									
Aberration no. and name	feed cons. (g/hen. day)	water cons. (cl/hen. day)	hen-day egg production (%)	second grade eggs (%)	floor eggs (%)	egg weight (g)	body weight (g)	cumulative mortality (%)	flock-uniformity (%)	ambient temperature (°C)
Detection of diseaeses										
1. Respiratory disorder	-	-	-	+	+					
2. Osteomalacia	-	-			+	-			-	
3. Digestive disorder		+	-	+		-	-			
4. High and fast mortality		+						+		
5. Parasites	-		-							
Control of ambient temperature										
6.Extreme hot day	-	+		+		-				+
7.Extreme cold day	+									-
Control of feed consumption										
8. Major feed restriction	-		-	+		-	-			
9. Major water restriction	-	-	-			-				
10. Change in feed composition	-	+	-	+		-				
11. Disturbance in feed installation	-									
12. Disturbance in water installation		-								

Table 8 shows the minimum and maximum deviations of the quantitative variable, that were estimated by the experts and incorporated into the ES. The deviations were also separated into the classes starting, advanced and serious. The minimum and maximum deviations were taken from the minimum and maximum values of the aberrations in which that variable was present (table 6). Because both flock-uniformity and cumulative mortality were only present in one aberration table, the minimum and maximum deviations were the same for these two variables. Table 8 also shows the results of the daily variation of quantitative variables that can be expected in flocks housed in an aviary system. Feed consumption, for instance, varies between 2.8 and 5.2 % per day. This means that deviations less than 5.2 % might be a coincidence, and that the ES or the expert should not react to such deviations.

Table 7. Variable Certainty Factors (VCF) of the 75, 90 and 95 percentiles for five standards and three detection limits (TS = theoretical starting; TA = theorethical advanced; PR = practical).

Aberration	Percentile	P75					P90					P95					Detection limits		
	standard	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	TS	TA	PR
Respiratory disorder		3	8	5	5	5	5	9	8	8.2	8.2	5	9	8.6	9	9	5.3	9.4	6.0
Osteomalacia		1	3.6	2.8	2.7	2.7	2	4.3	3.6	3.6	3.6	2	4.9	4.2	4.2	4.2	4.1	6.8	5.0
Digestive disorder		1	2.8	3.6	2.8	2.8	2	4.4	5.2	7	7	2	6	7	7	7	6.4	8.4	7.0
High/ fast mortality			1	2	2	2		2	2	2	2		2	2	2	2	1.9	5.2	3.0
Parasites		2	2	2	2	2	3	3	3	3	3	3	3	3.7	3.7	3.7	1.9	3.6	3.1
Extreme hot day		2	4	4	5.2	5.1	7	7	7	7	7	7	7.3	7	7.3	7.3	6.9	8.9	7.1
Extreme cold day		2	2	4	2	2	6	6	6	6	6	6	6	6	6	6	2.8	6.4	6.1
Major feed restrict.		1.9	3.7	3	3	2	4.6	5.8	5	8	8	8	8	8	8.2	8.2	4.8	8.8	6.0
Major water restrict.		3	5.1	4	4	4	4	7.2	5.8	6	6	4.6	7.2	6.6	7.2	7.2	3.4	6.4	6.0
Change feed comp.		4	5	5.2	5	5	5	6	6.4	6.2	6.2	5.8	7	7	7	7	6.4	8.1	7.0
Disturb. feed install.		0	0	0	0	0	3	3	3	3	3	3	3	3	3	3	3.0	6.0	4.0
Disturb. water install.			3	0	0	0		3	0	3	3		3	3	3	3	3.0	6.0	4.0

3.3 Validation

Figure 1 shows the results of the sensitivity and the specificity of the ES, when different standards and detection limits are used. The sensitivity is highest for the detection limit 'starting' and lowest for the detection limit 'advanced'. In general, when the sensitivity decreases the specificity increases, as can be seen in figure 1. Compared to the other standards the sensitivity of the LSL-standard is the lowest, and the sensitivity for the overall curves is highest. Compared to the other standards the specificity of the overall curves is lowest. The specificity and the sensitivity for the extrapolation standards MA3 and MA7 is almost the same, which means that averaging over more than 3 days adds nothing to the sensitivity of the extrapolation method.

Table 8 . Minimum and maximum deviations per variable estimated by the experts, versus the minimum and maximum coefficients of variation of real flock data (Lokhorst,1996b)

	Expert estimations -starting -advanced -serious		Coefficients of variation based on real flock data	
	min	max	min	max
feed consumption	1	10	2.8	5.2
	3	30		
	5	50		
water consumption	0.5	10	3.6	4.8
	3	30		
	5	50		
Ambient temperature	9	18	4.9	10.6
	20	24		
	30	35		
hen-day egg production	0.5	1	1.9	4.0
	1	4		
	2	9		
egg weight	0.1	1	0.8	2.0
	1	2		
	2	3		
body weight	2	2	1.0	1.1
	3	5		
	5	8		
flock uniformity	3	3	3.6	5.7
	10	10		
	25	25		
second grade eggs	1	5	9.1	45.1
	3	15		
	4	25		
floor eggs	1	2	4.8	19.5
	3	4		
	5	10		
cumulative mortality	1	1	1.7	6.7
	3	3		
	5	5		

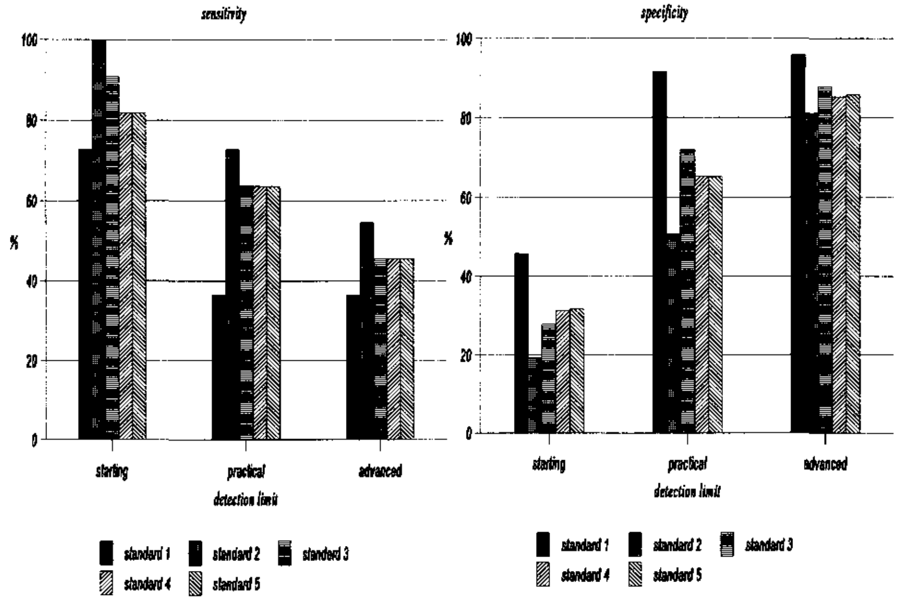

Fig. 1. Sensitivity and specificity of the ES, using five standards and three detection limits.

4. Discussion

4.1 Development of ES

Tracing aberrations in the production process is aimed at looking for exceptional variation in several variables. The knowledge of five experts was used to mimic the daily process of looking at the flock data and the comparison of these data with standards. The technique of aberration tables, of which table 4 gives an example, worked well. Using these tables, the communication between the knowledge engineer and the experts is very direct. Another advantage of the aberration tables is that the ES, which consists of a set of aberration tables, can easily be adapted or extended by altering the content of an aberration table or by creating a new one. It is not necessary to pay attention to the inference mechanism, because this is standardised too.

When detecting aberrations to do with the three CSFs, the best results are obtained when both quantitative and qualitative data are measured. If only quantitative data are used it is possible to give main causes. Qualitative data are needed for a further diagnosis of the problem. Quantitative data can be measured routinely and sometimes this can even be automated The advantages of automatic data collection include consistent accuracy, fewer transcription errors and the fact that the process is time consuming. Monitoring is a daily activity, so there is a great need to automate the data collection.

The experts used ten quantitative variables to detect the aberrations in the production process. From the results in Table 6 it can be concluded that it is necessary to look at combinations of quantitative variables. The formula for the calculation of the VCF is used to combine the deviations of different variables. This formula only takes account of starting, advanced and serious deviations that strengthen a certain conclusion.

The results in Table 8 imply that the experts may not have been aware of the magnitude of the normal process variation. The starting, advanced and serious deviations of the production variables were estimated by the experts to detect exceptional process variation, but most of the estimates of the starting deviations and some of the advanced deviations were lower than the minimum coefficient of variation. Serious deviations estimated by the experts can be classified as exceptional variation, and are therefore good indicators of aberrations. The consequence of having starting and advanced estimated deviations that fall within the natural daily process variation is that the number of false positive warnings of the ES will be high. This is in accordance with the results from Table 7 and Figure 1. The experts probably wish to be warned by the ES that something is wrong, but they also wish to be able to decide for themselves which are the real problems. Therefore, it is important for the poultry farmer or expert to be able to see the data on which the conclusion is based. The option of the subsequent diagnosis, which is based on qualitative data, also shows that the experts are not afraid of false warnings, but that they themselves wish to do part of the monitoring process.

From Table 8 one can also see that the normal process variation differs between quantitative variables. The normal variation of the second grade eggs and floor eggs can become so high, that one can doubt their usefulness for monitoring the daily production process in aviary systems for laying hens.

4.2 Standards and detection limits

The success of the monitoring of aberrations depends on which standards and detection limits are chosen (Figure 1). In practice, poultry farmers mostly work with standards supplied by the breeding farms, but in this research four other standards were tested too. The LSL standard is much less sensitive than the other four standards. This standard consisted only of weekly hen-day egg production, feed consumption and egg weight data. Other essential variables were not present in the standard and therefore the aberrations 'High and fast mortality' and 'Disturbance in the water installation' could not be detected (Table 7). The other aberrations could be detected, but not all possible variables were used. These results cast doubt on the usefulness of the LSL standard in the ES.

The two standards that were based on mathematical curves (standards nos.2 and 3) generally showed the highest sensitivity. The overall curves that were based on an average of six flocks (Lokhorst, 1996b), showed even more sensitivity than the flock-specific curves. The conclusion from this is that it is dangerous to select a standard that is closely related to the real production. This also explains the lower sensitivity of standards that were based on the extrapolation of the real flock results (standards 4 and 5). This lower sensitivity can be explained by the fact that gradual changes are incorporated into the standard, and therefore are no longer noticed by the ES. A disadvantage of the overall mathematical curves compared to the flock-specific curves is that their specifity is lower.

Because the difference in specificity between the overall curves and the flock-specific curves is greater than the difference between sensitivities, one can conclude that the flock-specific curves are slightly better.

There are no differences between sensitivity and specificity for the two extrapolation standards (standards 4 and 5). This means that averaging data over three days produces the same results as averaging data over 7 days. The sensitivity of these two standards is comparable with the curve standards, but the specificity is somewhat lower.

The influence of the detection limit on the sensitivity and the specificity is clear (Table 7, Figure 1). The choice of the detection limit probably depends on the final use of the ES. If the ES is used for a first screening of the data it is important for the sensitivity to be high. In this case the poultry farmer is aware of the fact that specificity is low. Nevertheless, he knows that when no warning from the screening is present, there are no problems in the production process. If, on the other hand, the ES replaces the poultry farmer's monitoring task, both sensitivity and specificity should be high. In this case, a false warning can stress the poultry farmer, because he expects there to be a real problem in the production process. In this case a compromise between an acceptable sensitivity and specificity, the practice detection limit, can be used. The sensitivity and the specificity of the flock-specific standard are then respectively 63.6 % and 72.1 %. The ES has been implemented in LayVision, which can easily switch between standards and detection limits.

5. Conclusion

From the results presented, one can conclude that it is possible to build an ES that is capable of manipulating daily quantitative and qualitative data from a poultry flock. Standardising the inference mechanism and the knowledge representation produces a tool that is flexible, and minimises the effort of the poultry farmer in that he can choose whether or not to analyse further possible aberrations. The ES can work solely with quantitative data that can easily be measured in the house, but the monitoring of the daily production process will be better if qualitative data are also used. The ES has been incorporated in the DSS LayVision which makes it very easy to use different standards that can be connected to the daily data on a flock. The choice of the standard and the detection limit influences the sensitivity and the specificity of the ES. If the ES should 'replace' the farmer's monitoring task, it is recommended to use flock-specific mathematical curves as standard, and a set of practice detection limits. It is expected that the knowledge of the experts will enable the farmer to monitor the critical success factor areas of the control of the feed consumption, to control the ambient temperature and to successfully detect diseases early.

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Chapter 8

General discussion

General discussion

In the present chapter the results described in this thesis will be discussed in relation to the research questions. Some conclusions and needs for future research will also be discussed.

1. Evaluation of the research methodology

The work of this thesis involved using common research techniques, such as literature research, experimentation and statistical analysis. These are so widely used that they will not be discussed in detail here. The statistical techniques used in chapter 3 (ordinal logistic regression), in chapter 4 (generalised linear mixed models (GLMM)), and in chapter 5 (generalised linear models (GLM)) are recent variants of the better known regression analysis and analysis of variance.

The technique for counting and weighing eggs per laying nest developed is new. Until now it was only technically possible to count eggs per row of laying nests. However, to satisfy the need for more detailed information on egg production in the aviary house it is necessary to count and weigh eggs within a full row of laying nests. The basic idea is that certain diseases or technical disorders may start very locally in the henhouse and then spread through the house. Those aberrations can be detected at an early stage only if the egg production and other variables can be measured very locally. By developing the Egg Weighing And Counting System (EWACS) and using it to collect detailed data on egg weight and the number of eggs per group of five laying nests it was demonstrated that there was a large day-to-day variation per laying nest. This means that it is not effective to detect aberrations on the basis of data per laying nest or per small group of laying nests.

The new technique of weighing and counting eggs has other possible applications. Breeding companies could use EWACS to lower costs because it would enable them to cut down on manual labour to collect and weigh eggs. EWACS could also be applied in commercial cage systems, where it would be easier to apply because the cages are separate and contain a few hens, whereas in the aviary housing system hens are free to move around. An interesting option would be to combine the detailed information that can be gathered with EWACS with the possibility to dispense feed per cage. The latter is already commercialised.

The techniques of individual recognition of laying hens and automatic weighing are combined in the prototype of the Individual Poultry Weighing System (IPWS). This is the first time that these techniques have been combined and applied in the the poultry sector. Previously, researchers studying behaviour or the application of automatic weighing systems assumed that many different hens are visiting the weighing scales. Sometimes they marked a number of hens with colours and they made visual or automatic recordings during parts of the day. The IPWS makes it possible to follow many different hens continuously. The technique of recognising individual laying hens proved its usefulness in the study of the accuracy of automatic weighing systems in aviary systems, but it has other promising applications. The IPWS can also be used to improve the efficiency of weighing birds on breeding and broiler farms. The technique of recognising individual hens automatically could also be very useful in studies on hen behaviour in small and large groups.

The technique of non-linear regression for describing variables of the egg production process has been used very often by other researchers in this field. This is logical since the production process is a biological process which is non-linear by nature. However, the non linear regression technique has mostly been used to describe the hen-day egg production and the egg weight. Variables such as feed consumption, cumulative mortality, and percentage of second grade eggs are generally assumed to be linear, while others such as percentage of floor eggs, flock-uniformity, and water consumption are not modelled at all. Because of the intrinsic non-linearity of the production process in this research all relevant production variables were described by a non-linear mathematical curve. These curves have the disadvantage that changes in the values of the parameters are more difficult to interpret, but their advantages are 1) only a few parameters are needed per variable, 2) the curves easily can be adapted to flock-specific circumstances, and 3) they enable the 'normal' variation of a variable to be ascertained (chapter 6). This third advantage is especially important, since aberrations in the production process are recognised by the 'exceptional' variation, i.e. deviations outside the range of 'normal' variation.

The technique used to store the data in a knowledge base is novel. Vanthienen and Wets (1994) used a similar technique when they applied decision tables as a basis for an expert system. The aberration tables presented in chapter 7 were developed to facilitate useful exchange of information between the experts and the knowledge engineer. The experts appreciated the simple tables, as these helped them to become aware of the decision rules they use.

2. Practical implications of the research findings

2.1 Economic implications

In chapter 2 it was pointed out that the economic aspect is important in both the short (efficient production) and the long (farm profitability) term. The cost price of eggs is an important variable for the poultry farmer. The production costs of eggs from aviary, perchery and multi-tier housing systems with 20 hens per m^2 ground floor area are still 5 to 8 % higher compared with cage systems with 450 cm^2 area per hen. The cost price for eggs from deep litter housing systems with 7-10 hens per m^2 ground floor area is 18% higher compared with cage systems (Elson, 1985; Appleby et al, 1992).

The basic question is whether consumers recognise the production systems as welfare friendly and whether they are prepared to pay more for eggs from these systems than for eggs produced in cage systems. Consumers' wishes are not always consistent. Mettler and Lagergren (1993) describe that the Swiss banned cage systems in 1978 by a large majority in a referendum, but that still 35 - 40 % of eggs imported into Switzerland are from cage systems. It is expected that the same will happen in Sweden, where cages will be banned in 1999 (Sørensen, 1995).

If aviary systems are introduced as an alternative to cage systems the producers' cost price will be higher and farmers will probably demand an extra premium for the eggs. This is the present situation in the Netherlands. On the other hand, if aviary systems are seen as an alternative to deep litter systems, they can be characterised as an efficient variant of the deep litter system, and no extra premium is needed.

It is expected that future legislation will aim to give hens more space in cages, e.g. with minimum requirements 600 cm^2/bird. Then the cost price of eggs produced in cage systems will be at the same level as the cost price of eggs produced in aviary systems (Appleby et al., 1992) and the choice facing the consumers will become more economic.

To get an idea of the costs of aberrations in the production process, the mathematical curves from chapter 6 were used to calculate the economic consequences of two actual aberrations (Lokhorst, 1996). For a flock of 20,000 hens, a feed price of 0.493 Dfl/kg and an egg price of 1.71 Dfl/kg, an aberration in the water distribution resulted in a net production loss of 785 Dfl. A complex aberration, which consisted probably of a combination of an IB infection, a TRT infection, worms and the fact that the hens were early in production with a low feed consumption, resulted in a permanently lower hen-day egg production of 4 % and as a consequence, in a net loss of 25,422 Dfl. This shows the economic importance of the early detection of aberrations in the three critical success factor areas and the savings that could be achieved by using a decision support system like LayVision to monitor the daily egg production process.

2.2 Use of daily data

To support the decisions concerning the critical success factors it is important to have up to date information quickly on actual and possible diseases, feed consumption and production results. Given the main objective of the study, it is clear that information should be available from day to day. This contrasts with the existing information use on commercial farms. At present some data are collected daily, some weekly and others only a couple of times per production cycle. These data are used to produce production reports per week, per four weeks or per complete production cycle. This implies that the information gathered in the poultry house will be interpreted too late to be useful for operational management purposes. Another disadvantage of weekly reports is that deviations in the production results of some days are averaged or smoothed, and consequently are not detected in time. The time horizon of the data collection (day) is inappropriate for the time horizon of the information use (week), which implies that information is lost. By measuring data daily and by transforming it into information that is used daily, the period between successive control actions is shortened to not more than one day. In this thesis attention is also paid to the quality of the measuring of the data, the transformation of these data into information, and the comparison with a reference value or standard. The last step in the control cycle, the corrective action, has not yet been worked out.

The research directed on the technique of measuring data in an aviary system was limited to certain output variables. The quality or usefulness of data vary, depending on where and when they are measured. This is why this thesis includes recommendations on how to measure the egg weight, the number of eggs, the body weight and the flock-uniformity in an aviary housing system. Standardising of the measuring techniques and the procedure to measure data will make comparisons with data between flocks or with reference values more useful.

The day-to-day variation is not the same for all input and output variables of the production process in aviary houses. The 'normal' day-to-day variation, expressed by the minimum coefficients of variation for the flock with respectively the lowest day-to-day variation and the maximum coefficient of variation for the flock with the highest day-to-day variation is 1.9 - 4.0 % for the hen-day egg production, 0.8-2.0 % for the mean egg weight, 4.8-19.5 % for the percentage of floor eggs, 9.1-45.1 % for the percentage of second grade eggs, 2.8-5.2 % for the feed consumption, 3.6-4.8 % for the water consumption, 1.0-1.1 %for the mean body weight, 3.6-5.7 % for the flock-uniformity, 1.7-6.7 % for the cumulative mortality, and 4.9-10.6 % for the ambient temperature (chapter 6). From this it can be concluded that the percentage of floor eggs and the percentage of second grade eggs show large day-to-day variation, and that certain other variables also have a considerable day-to-day variation. This can be problematic. The 'exceptional' process variation defined by experts as indicating starting aberrations falls within the category of 'normal' day-to-day variation, and therefore it is possible that the experts will react on the basis of wrong signals and that the production process will become instable. Before the farmers/experts perform a corrective action they must carefully consider whether there really is an aberration. Sometimes it is even necessary to gather more information. Having a relatively large 'normal' variation makes it impossible to detect aberrations that are classified as starting. On the other hand, aberrations that are classified as 'advanced' and 'serious' can be detected indeed from the daily data. The 'exceptional' process variation defined by the experts for these two categories is larger than the 'normal' process variation.

There are several options for solving the problem of a relatively large 'normal' day-to-day variation. First it is important to recognise that the day-to-day variation can be influenced by the measurement technique chosen and how, when and where it is used. The accuracy of the non-automated data colection of the poultry farmer probably also plays an important role in the variability of the data. A smoothing or averaging technique can be used to minimise the random daily variation in the data (Makridakis et al.,1983). The variation in the number of eggs per compartment can be reduced by averaging data over a couple of days. The coefficient of variation is reduced to 1 % when egg number data are averaged over four days. The coefficient of variation of the mean egg weight can be reduced to 1.6 % when an EWACS is used, or if data are averaged over a couple of days. The coefficient of variation of the mean body weight and the flock-uniformity can be reduced by using more weighing scales per compartment, by averaging data over a couple of days or by improving the automatic weighing system. With the current automatic weighing system only 60% of the hen visits resulted in a successful weighing, so there is much space for improvement.

Secondly it can be advised to examine the processes more closely. Since highly sophisticated process computers are used to control the ambient temperature and to control the feeding of the hens, it seems justified to assume that these processes are controlled in such a way that they fall within a predetermined tolerated range and are stable. An examination of the data and the day-to-day variation raises doubts about this assumption. The 'normal' and 'exceptional' variation in the production process needs to be examined more closely. If the variability can be reduced, the quality of the production process will also improve.

The third option is to have a closer look at the experts. It is unlikely that they are aware of the day-to-day variation that occurs. They are used to working with weekly data, and the week-to-week variation is much smaller than the day-to-day variation. On the other hand, the experts may be aware of the day-to-day variation. They would then rely on their own knowledge to judge the data and to say whether the variation is normal or exceptional. The basic idea of working with standards (reference values) and daily data is acceptable, but must be worked out further.

2.3 Production unit

In chapter 2 the term 'production unit' was introduced to signify a group of hens that can be managed separately by the poultry farmer. It was stated that technical production results as well as economic results should be gathered per production unit and that the production unit on farms with an aviary housing system will be a flock that is housed in the whole henhouse or a sub-flock that is housed in a compartment. The concept of production units emphasises the possibility of having a number of smaller units within a farm that can be handled separately. The more is known about a unit, the better it can be managed.

The term production unit can also be applied to whole farms that are part of a larger organisation, or an integration. The general trend is for these production units (poultry farms) to increase in number and for flocks and houses to become bigger (Swarbrick, 1995). These larger production units generally have better management, husbandry, equipment and nutrition results because they have 'to stay in business' (Swarbrick, 1995). It seems contradictory, but the efficient large production units consist exclusively of cage systems, in which it is possible to manage sub-units. So, for a large scale application of aviary housing systems it can be recommended to subdivide the farm into a number of production units.

At this stage of the research it is not possible to give a clear answer about the optimal size of a production unit. This depends on factors such as the effort needed to measure technical and economic data, the effort needed to separate groups of hens, the nuisance of extra obstacles in the henhouse, the frequency and severity of different types of aberrations in the production process, and the possible reduction of losses. For each farm and farmer the optimal situation will probably be different.

More insight is needed into the outbreak and spread of diseases. If for instance a disease is limited to a small number of hens and spreads slowly, it can be advised to make production units as small as possible. This will make it easier to detect this disease and a second advantage would be that there is an extra barrier hindering the spread of the disease. If a disease spreads rapidly through the henhouse there will be no differences in its detection between small and large production units. In any way, for the detection of diseases it can be advised to have small production units.

If production units are controlled separately more equipment, such as engines, valves and pipes are needed. This increases the probability of technical aberrations. However, the consequences of these aberrations are less in smaller units than in larger units. Somewhere there will be a balance between the higher risk on technical aberrations at farm level and the possible losses.

For monitoring purposes it should be possible to measure the relevant technical production data, such as egg numbers, egg weight, feed consumption, water consumption, ambient temperature and body weight per production unit. At this stage of research it is not worked out yet what the added value of economic data per production unit will be.

Additional advantages of relatively small production units are that eggs are distributed more evenly over the egg belts, the heat production of the hens is distributed more evenly and the danger of accumulation of hens is less (Lokhorst et al, 1994). Because the ambient temperature will be distributed more evenly it can be expected that there will be less variation in the production variables, and this will improve the controllability and the quality of the production process. Having more smaller production units makes it easier to perform within-farm comparisons.

What is an acceptable size for a production unit ? If, e.g. a TWF aviary house for 20,000 hens is subdivided into 8 compartments, each compartment will be 7 m wide and approximately 15-20 m long, if 20 birds are housed per m^2. Per compartment a group of 2,500 hens will be housed. In Switzerland, for instance, the size of a henhouse is limited to 3,500 hens. The main reason for this is to spread the risks of aberrations in the production process.

2.4 Monitoring the production process

The decision support system (DSS) LayVision was developed to support the three critical success factor (CSF) areas. In our tests, data from the aviary houses were stored in the commercially available management information system GACLEG. In order to enable GACLEG to present daily instead of weekly data, the option to export the daily data to LayVision was added to GACLEG. LayVision is a DSS that helps the farmer to analyse the recorded daily data. Its most important features are 1) the connection with GACLEG, 2) the graphical presentation of the daily data and standards, 3) mathematical curves that describe daily input and output variables , 4) a calculator to perform simple calculations and 5) an expert system (ES) to evaluate the daily production process. In this thesis only two elements, the mathematical curves in chapter 6 and the ES in chapter 7, are described in deatil. But the other elements are also important. The user-interface, for instance, must be so provocative that users will want to use the DSS. Therefore all variables are presented as graphs. Flexibility is the key analysing the data. A farmer who wants to analyse the data himself must be able to calculate new variables or to combine existing variables. This is why a calculator is incorporated.

The ES focuses on the monitoring of the daily production process. From the analysis of the experts it follows that 12 main aberrations can be distinguished in the three CSF areas. Originally it was intended that only quantitative data should be incorporated in the ES because they can easily be measured in the henhouse and their collection can be automated. However it was also necessary to incorporate qualitative data such as the colour of the faeces or the abnormal colour of eggs, into the ES. This results in another use of the ES. The ES component using the quantitative data now focuses on a first screening of the production process. The poultry farmer is responsible for the final detection and analysis of the real problems. He does so by using qualitative information about the production process, by using the ES, and by consulting other experts such as veterinarians and advisors.

The validation of the ES was limited to an internal validation and a pre-test based on the use of quantitative data. A field test in which the qualitative data are also incorporated still has to be carried out. This makes it difficult to give a final conclusion on the practical use of the ES. However, one can conclude that the ES successfully integrates both quantitative and qualitative information. Because the ES should run daily for each production unit, it is advantageous that it works primarily with quantitative data.

The sensitivity and the specificity of the ES are strongly influenced by the choice of a reference value or a standard and a detection limit (chapter 7). If one wants to look at the overall flock results it is advisable to use a standard from the breeding company or the average flock results of a feeding company, district or country. However, these standards are not appropriate for use in the ES. It is suggested to use the overall mathematical curves as a standard. It is possible to make these general curves flock-specific, but there is then a possibility that a gradual decrease or increase in the values of the different production variables will be included in the standard. If this happens it is impossible to detect a gradual increase or decrease in the production. This danger is also present when a moving average or an extrapolation of the actual flock data is used as a standard. By choosing a practical set of detection limits a balance is found between an acceptable sensitivity and an acceptable specificity. Nevertheless, there is still the challenge of improving both sensitivity and specificity.

3. Conclusions

The following conclusions can be drawn from this research:

- The day-to-day management using daily information, instead of weekly or four weekly information, should at least concentrate on the following critical success factors: control of the feed consumption, control of the ambient temperature, and early detection of diseases.
- Management tools should primarily aim at the operational control of the three critical success factors.
- The Egg Weighing And Counting System is highly useful for counting and weighing eggs in experimental situations, since it gives very detailed information on the egg production.
- Automatic weighing systems without individual hen recognition can deliver reliable management information on mean body weight and flock-uniformity in aviary housing systems.
- Individual hen recognition by means of transponders is very useful to study the use of automatic weighing systems and to improve their quality.
- The day-to-day variation in the number of eggs, the egg weight, the body weight and the

flock-uniformity depends on the measuring techniques applied and where and when the measurements were done.
- In an aviary housing system the compartment is the smallest production unit for which it is useful to collect production data.
- The economic consequences of aberrations in the production process make it worthwhile to use a decision support system like LayVision to support the monitoring task of the poultry farmer.
- Non-linear mathematical curves are very useful for describing the production process in aviary housing systems for laying hens and to ascertain the 'normal' variation in the production variables.
- The results of the expert system are clearly improved if both quantitative and qualitative data are used.
- The success of the detection of aberrations in the production process with the expert system depends on the standard and detection limit chosen.
- A standard based on mathematical curves functions well in the expert system.
- Starting aberrations in the production process still cause too many false warnings. Aberrations that can be classified as advanced and serious can be detected successfully by the expert system.

4. Future research

The main avenues for future research are:

- Before the decision support system LayVision is tested in a practical situation, a further analysis of the use of different types of standards is needed. It is clear that the choice of a good standard influences the operational planning and operational control process.
- LayVision works only with production data. Extending it with financial data would enable it the production process to be optimised in such a way that the economic consequences of decisions are also incorporated.
- LayVision has been developed to facilitate the management task of a poultry farmer with an aviary system, but with a few modifications it could also be used for other poultry housing systems. If it is used in other housing systems, special attention must be paid to the characteristics of data gathered in those housing systems.
- Detailed information on some output variables of the production process was gathered, but it is also necessary to have detailed information on the input variables, ambient temperature, feed consumption and water consumption.
- The mathematical curves can be used to calculate the consequences of the size of compartments. Before this is done, more needs to be known about the occurrence and severity of aberrations.
- If LayVision is to be successfully introduced in practice, most of the production data will have to be gathered and stored automatically in a management information system.
- Special attention must be paid to minimising the day-to-day variation in the data. It is expected that the technique of Statistical Process Control (Deming, 1986) could be very useful for stabilising the production process.
- At present the expert system concentrates on the data of just one day. It would be advisable to study the feasability of incorporating data from preceding days too.

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Daily management support in aviary housing systems for laying hens

Summary

Summary

1. Introduction

Aviary housing systems have been developed to benefit the welfare of laying hens and to be an economically viable alternative to cage systems. However, they require a different management strategy than housing systems with cages. Furthermore, the feed consumption and the housing costs are higher in aviary systems and there is more variation in the production results. It results in a cost price of eggs produced in aviary systems being 7-15 % higher than of eggs produced in a three-tiered cage system. Because hens in aviary systems have more contact with their droppings (litter) and with other hens, there is also a greater risk of some infectious diseases.

To control the cost price and the increased variation in the production process the poultry farmer needs to know what is going on in the aviary house. A good registration and analysis of daily production and health data would help him to identify diseases or abnormal production circumstances at an early stage, and therefore enabling him to take appropriate measures in time, thereby minimising potential production losses. The research objective therefore is: 'To support the poultry farmer in his day-to-day management by improving the control of the production process in aviary housing systems for laying hens on the basis of data collected daily'.

The research aims to answer three general questions:

- Is it possible to describe the daily management needed to control the production process in aviary systems for laying hens ?
- What are the characteristics, e.g. accuracy, of data measured daily in aviary systems and what reliable information can be generated from these data ?
- What management tools can be developed to support the daily management to control the production process in aviary systems for laying hens ?

2. Description of daily management

Chapter 2 describes the goals of a hypothetical aviary farmer, his critical success factors and information needs and the selection of an appropriate management concept. Assuming that the poultry farmer manages his farm in an economically sound way, the next goals can be formulated 1) the efficient production of high quality eggs, 2) the welfare friendly treatment of hens, and 3) the long-term profitability of the farm. The daily management focuses mainly on the control of feed consumption and ambient temperature and the early detection of diseases. These are the three main critical success factors (CSF). Timely and reliable daily information is needed per production unit on feed consumption, egg production and diseases. The Poultry Information Model is adopted as a suitable management concept, because it has already been introduced and accepted in the Dutch poultry sector and because it describes the levels of strategic, tactical and operational management in detail. From an analysis of the operational management functions 'operational planning', 'implementation' and 'operational control' for the three critical success factors it is concluded that poultry farmers pay scarce attention to 'operational planning'. For the 'implementation' the poultry farmers rely on sophisticated process computers. However, 'operational control' requires much attention from the poultry farmers. Therefore it is recommended that management tools primarily must be aimed to support the 'operational control' of the three critical success factors.

3. Characteristics of measured data

Special attention is paid to the characteristics of the output variables: number of eggs, mean egg weight, body weight and flock-uniformity. Advice is given on how to measure these variables in an aviary house and the consequences of this for the accuracy of the measured data are explained.

To ascertain the variation of the egg production within an aviary house an Egg Weighing and Counting System (EWACS) is developed. It counts and weighs eggs per group of laying nests. The prototype of the system and results from laboratory tests are described. When adjusted correctly, EWACS can be used in aviary housing systems and gives a detailed view of the egg production. EWACS is used to count and weigh eggs twice a day from 32 blocks of five laying nests each. The blocks were divided over 2 tiers of laying nests in a compartment of an aviary system. After the first 3 weeks of the laying period, the distribution of eggs over the laying nests within a tier became stable. If eggs from only one nest group are counted daily the coefficient of variation is 23.1 %. If the eggs from the whole compartment are counted daily, the coefficient of variation for the number of eggs is 2.8 %. The daily number of eggs varies according to nest group, whether the group is next to a partition and according to the level of the tier. The distribution of the mean egg weight over the different laying nests within a tier is stable for the whole laying period. The coefficient of variation of the daily mean egg weight for a nest group is 3.1 %. It can be concluded that egg numbers cannot be estimated reliably by taking samples from a group of laying nests or a tier, but that it is necessary to count all the eggs from a compartment. The daily mean egg weight, however, can be estimated reliably from a sample of eggs from a group of laying nests or a tier. EWACS enables frequent samples to be taken, which diminishes the coefficient of variation.

An Individual Poultry Weighing System (IPWS), consisting of four weighing scales with antennas, is developed to record individual hen weight and the time, duration and location of their visits to the weighing scales. Individual hens are recognised by means of transponders attached to their legs. IPWS is used to investigate, when and where the body weight and the flock-uniformity should be determined in an aviary system if automatic weighing systems are used. The number of hens visiting the weighing scales per three-hour period varies from less than 10 during the dark period to over 60 during the light period. During the light period the mean number of visits of a hen to the weighing scales is 1.4 and mean number of succesfull weighings per hen then is 0.6. Body weight shows a diurnal rhythm and the mean difference between the maximum body weight at night and the minimum body weight in the morning is 63 g. The number of visits, number of weighings, mean body weight, flock-uniformity and the duration of the visits depend on the location of the weighing scales. Fifty-four percent of the hens visiting the scales during a 24-hours period, visit them only once and the average duration of the visits to the scales in the middle of the feed tier during the light-period is 63 s. It is concluded that automatic weighing systems without individual hen recognition can deliver reliable management information on mean body weight and flock-uniformity in aviary systems if the weighing scales are located on the feed tier in the middle of the house and if they are used during the light period.

From the experiments with EWACS and IPWS it can be concluded that the day-to-day variation in the data can be influenced by the choice of the measurement technique. The day-to-day variation can be reduced in several ways, but in most cases this also means extra investment. The expected day-to-day variation is 2.8 % for egg numbers when eggs are counted per compartment, 3.1 % for the mean egg weight when a pile of six egg trays is weighed, 1.1 % for the mean body weight when four weighing scales are used and 1.9 % for the flock-uniformity. The variation in the number of eggs per compartment can be reduced to 1 % by averaging egg number data over four days. The coefficient of variation of the mean egg weight can be reduced to 1.6 % by using EWACS, or by averaging data over a couple of days. The coefficient of variation of the mean body weight and the flock-uniformity can be reduced by using more weighing scales per compartment, by averaging data over a couple of days or by improving the weighing technique.

4. Management tools

Data from experiments in aviary houses are input into LayVision, a decision support system (DSS) developed to support the three CSF areas and to analyse the daily data. Two parts of the DSS, the mathematical curves and the ES are described more precisely.

Using literature data and data collected from six non-moulted flocks housed in aviary system, mathematical curves describing the daily production process in terms of the input variables daily feed consumption, water consumption, ambient temperature and output variables hen-day egg production, egg weight, second grade eggs, floor eggs, cumulative mortality, body weight and flock-uniformity are drawn to describe the production process in an aviary housing system. These curves are also used to ascertain the day-to-day variation of these variables. All curves are a function of the number of days in the laying period. The curves for the cumulative mortality, hen-day egg production, egg weight, body weight and percentage of floor eggs describe the individual flocks results well ($0.72 < R^2_{adj} < 1.00$). The coefficients of determination for the feed consumption, water consumption, flock-uniformity and the percentage of second grade eggs are in general low ($0.33 < R^2_{adj} < 0.54$), which implies that the form of the curve can differ between flocks. Egg weight, body weight, cumulative mortality and hen-day egg production have 'minimum' coefficients of variation (CV= 0.8 - 1.9 %), and therefore show the smallest day-to-day variation, followed by feed consumption, water consumption and flock-uniformity (CV = 2.8 - 3.6 %). The ambient temperature, percentage floor eggs and percentage of second grade eggs have the 'highest' minimum coefficients of variation (CV = 4.8 - 9.1 %). It is concluded that the mathematical curves can be used as standard or reference values for monitoring the daily production process. From the analysis it becomes clear that if the mathematical curves are used as reference value, they must be recalibrated regularly, using data on flock-specific circumstances, to ensure that the predicted values are close to the real production results. The overall parameter fits presented in chapter 6 can serve as a good starting point for properly setting the parameters for new flocks.

An expert system (ES) for monitoring aberrations related to the CSF feed consumption, ambient temperature and disease detection is developed to support the daily management on aviary farms for laying hens. Knowledge of 5 experts is stored in the knowledge base, which is built up from several aberration tables. These tables are used to standardise the knowledge representation and the inference mechanism of the ES. Detection of aberrations in the production process is based on quantitative and qualitative data. According to the experts, feed consumption, water consumption, ambient temperature, hen-day egg production, egg weight, body weight flock-uniformity, second grade eggs, floor eggs and mortality are important quantitative data. Data on four flocks and five different standards are used for the sensitivity analysis and the validation of the ES. This validation is limited to the internal validation and a pre-test based on quantitative data. The standard and detection limit chosen, influence the sensitivity and the specifity of the ES. It is suggested that the overall mathematical curves be used as standard. It is also possible to make these general curves flock-specific, but this might result in a gradual decrease or increase in the values of the different production variables being incorporated in the standard, and obscuring actual gradual increases or decreases. The choice of the detection limit depends on the final use of the ES. If the ES is used for a preliminary screening of the data it is important for it to be very sensitive. But if the ES replaces the poultry farmer's monitoring task, both, sensitivity and specifity should be high. In this case false warning can stress the poultry farmer, because he will then expect there to be a real problem in the production process. In this case a compromise between an acceptable sensitivity and specificity the practical detection limit can be used. The sensitivity and the specificity for the farm-specific standard are 63.6 % and 72.1 % respectively.

Preliminary calculations of the economic consequences of aberrations in the production process show that the net production loss can sometimes exceed 20,000 Dutch guilders. This shows the importance of the early detection of aberrations in the three CSF and the savings that can be obtained when a DSS like LayVision is used to monitor the daily egg production process in aviary housing systems for laying hens.

5. Conclusions

The following conclusions are drawn:

- The day-to-day management using daily information, instead of weekly or four weekly information, should at least concentrate on the following critical success factors: control of the feed consumption, control of the ambient temperature, and early detection of diseases.
- Management tools should primarily aim at the operational control of the three critical success factors.
- The Egg Weighing And Counting System is highly useful for counting and weighing eggs in experimental situations, since it gives very detailed information on the egg production.

- Automatic weighing systems without individual hen recognition can deliver reliable management information on mean body weight and flock-uniformity in aviary housing systems.
- Individual hen recognition by means of transponders is very useful to study the use of automatic weighing systems and to improve their quality.
- The day-to-day variation in the number of eggs, the egg weight, the body weight and the flock-uniformity depends on the measuring techniques applied and where and when the measurements were done.
- In an aviary housing system the compartment is the smallest production unit for which it is useful to collect production data.
- The economic consequences of aberrations in the production process make it worthwhile to use a decision support system like LayVision to support the monitoring task of the poultry farmer.
- Non-linear mathematical curves are very useful for describing the production process in aviary housing systems for laying hens and to ascertain the 'normal' variation in the production variables.
- The results of the expert system are clearly improved if both quantitative and qualitative data are used.
- The success of the detection of aberrations in the production process with the expert system depends on the standard and detection limit chosen.
- A standard based on mathematical curves functions well in the expert system.
- Starting aberrations in the production process still cause too many false warnings. Aberrations that can be classified as advanced and serious can be detected successfully by the expert system.

Ondersteuning van het dagelijks management op bedrijven met volièrehuisvesting voor leghennen

Samenvatting

Samenvatting

1. Inleiding

Volièrehuisvestingssystemen zijn ontwikkeld om het welzijn van leghennen te bevorderen. Een randvoorwaarde bij die ontwikkeling is dat zij economisch concurrerend moeten zijn met batterijsystemen. Het management bij volièresystemen verschilt van dat bij batterijsystemen. Een hogere voedselopname, hogere huisvestingskosten en een toegenomen variatie in de produktieresultaten zijn, in vergelijking met een drie-etage batterijsysteem, in belangrijke mate verantwoordelijk voor de 7-15 % hogere kostprijs van eieren die geproduceerd worden in volièresystemen. Vooralsnog zijn volièresystemen dus niet economisch concurrerend met batterijsystemen. Daarnaast is er een verhoogd risico op bepaalde ziektes, omdat hennen in volièresystemen meer contact hebben met hun uitwerpselen (w.o. strooisel) en omdat zij contact hebben met meerdere dieren.

De pluimveehouder moet weten wat zich in de stal afspeelt, om de toegenomen variatie in het produktieproces en daarmee de kostprijs, te kunnen beheersen. Verwacht mag worden dat een goede administratie en analyse van dagelijkse produktie- en diergezondheidsgegevens bij kunnen dragen aan een vroegtijdige opsporing van afwijkende produktieomstandigheden en/of ziektes. Potentiële produktieverliezen kunnen geminimaliseerd worden als tijdig maatregelen getroffen worden. Het doel van dit onderzoek is geweest: 'de pluimveehouder ondersteunen in zijn dagelijks management door de beheersing van het produktieproces in volièrehuisvestingssystemen voor leghennen te verbeteren door gebruik te maken van dagelijks verzamelde gegevens'.

In dit proefschrift is het onderzoek beschreven dat gericht is op de beantwoording van de volgende drie vragen:

- Kan het dagelijks management dat nodig is om het produktieproces in volièrehuisvestingssystemen te beheersen beschreven worden ?
- Wat zijn de karakteristieken van dagelijks gemeten gegevens in volièrehuisvestingssystemen, en met welke betrouwbaarheid kan hieruit operationele informatie verkregen worden ?
- Welke managementhulpmiddelen kunnen ontwikkeld worden om de controle op het dagelijkse produktieproces in volièrehuisvestingssystemen te ondersteunen ?

2. Beschrijving van het dagelijks management

In hoofdstuk 2 worden de doelstellingen van volièrehouders, de kritische succesfactoren, de informatiebehoefte, en de keuze van een geschikt management concept beschreven. Naast de primaire eis dat een bedrijf op een economisch verantwoorde manier gevoerd dient te worden, kunnen de volgende nevendoelstellingen van volièrehouders geformuleerd worden: 1) een efficiënte produktie van kwalitatief hoogwaardige eieren, 2) een welzijnsvrienlijke behandeling van de hennen, en 3) een op de lange termijn gerichte levensvatbaarheid van het bedrijf. Het dagelijks management moet zich in belangrijke mate richten op de volgende drie kritische succesfactoren: de beheersing van de voedselopname, de beheersing van de staltemperatuur en de tijdige opsporing van ziektes. Van iedere produktieeenheid op een volièrebedrijf is dagelijks tijdige en betrouwbare informatie nodig van de voedselopname, de eierproduktie en ziektes. Het 'Informatiemodel Pluimveehouderij' is gekozen als een geschikt management concept, omdat het reeds in de pluimveehouderij geïntroduceerd en geaccepteerd is en omdat het verschillende niveaus van strategisch, tactisch en operationeel management gedetailleerd beschrijft. Uit een analyse van de relaties tussen de managementfuncties van het beslissingsniveau 'operationele planning', 'uitvoering' en 'operationele bewaking' enerzijds en de drie kritische succesfactoren anderzijds volgt dat pluimveehouders beperkt aandacht schenken aan de operationele planning. Bij de uitvoering vertrouwen de pluimveehouders in de regel op geavanceerde procescomputers. De operationele bewaking vraagt veel aandacht van de pluimveehouders. Daarom is geadviseerd om de managementhulpmiddelen in eerste instantie te richten op de ondersteuning van de operationele bewaking van de drie eerdergenoemde kritische succesfactoren.

3. Karakteristieken van gemeten gegevens

Speciale aandacht is gegeven aan de karakteristieken van de output-variabelen: aantal eieren, gemiddeld eigewicht, diergewicht en de variatie in het diergewicht. Het laatste wordt uitgedrukt in het kengetal 'uniformiteit'. Geadviseerd is hoe deze gegevens in een volièrehuisvestingssystemen gemeten moeten worden. Tevens is de variatie van de gegevens in afhankelijkheid van de gebruikte meetmethode aangegeven.

Om het inzicht in de variatie van de eierproduktie binnen een volièrehuisvestingssysteem te vergroten is een eierweeg- en eiertelsysteem (EWACS) ontwikkeld. Het systeem telt en weegt eieren per individueel legnest of per groep legnesten. Zowel het prototype als de uitgevoerde laboratoriumtesten zijn beschreven. Een goed afgesteld EWACS kan gebruikt worden in een volièrehuisvestingssysteem om een gedetailleerd beeld te krijgen van de verdeling van de eierproduktie binnen de stal. EWACS is gebruikt om van 32 blokken die ieder bestaan uit vijf legnesten gedurende één legronde tweemaal daags de eieren te tellen en te wegen. De blokken zijn verdeeld over twee rijen legnesten. Gebleken is, dat binnen een rij legnesten de verdeling van het aantal eieren over de legnesten pas na de eerste drie weken van de legperiode stabiel wordt. De variatie -uitgedrukt als variatiecoefficient- in het dagelijks getelde aantal eieren van een blok, bedraagt 23.1 %. Als de eieren per afdeling geteld worden, bedraagt de variatiecoefficient voor het dagelijks aantal getelde eieren 2.8 %. Het aantal getelde eieren per groep legnesten is afhankelijk van de plaats van de legnesten en de aanwezigheid van een tussenschot direct naast de groep legnesten. De verdeling van de eigewichten binnen een rij is vanaf het begin van de legperiode stabiel. Als de eieren per blok gewogen worden, bedraagt de variatiecoefficient voor het gemiddelde eigewicht 3.1 %. Geconcludeerd is dat het aantal eieren per afdeling niet nauwkeurig geschat kan worden op basis van een steekproef van het aantal eieren van een blok legnesten. Het is noodzakelijk om alle eieren van de afdeling te tellen. Het gemiddeld dagelijks eigewicht kan echter wel betrouwbaar geschat worden op basis van een steekproef van eieren uit een blok legnesten. Met behulp van de EWACS kunnen meerdere waarnemingen per afdeling gedaan worden, hetgeen tot gevolg heeft dat de variatiecoefficient daalt.

Een Individueel Pluimvee Weeg Systeem (IPWS), enerzijds bestaande uit vier weegschalen met een antenne en anderzijds transponders die aan de poten van individuele hennen bevestigd zijn, is ontwikkeld om te herkennen welke individuele leghennen op ennweegschaal komen. Per bezoek van een leghen aan een weegschaal zijn de volgende gegevens geregistreerd: het diernummer, het tijdstip, de duur, de plaats, en het diergewicht. Het IPWS is gebruikt om te onderzoeken wanneer en waar het gemiddelde diergewicht van een groep dieren in een volièrehuisvestingssysteem gemeten moet worden. Op basis van de gemeten diergewichten wordt de uniformiteit berekend. Per periode van drie uur varieert het aantal hennen dat op een weegschaal komt van minder dan 10 in de periodes die in het donker vallen tot meer dan 60 in de periodes die in het licht vallen. Het gemiddeld aantal bezoeken per hen en het gemiddeld aantal succesvolle wegingen per hen, bedragen gedurende een periode van drie uur in de lichtperiode respectievelijk 1.4 en 0.6. Het diergewicht vertoont een dagelijks patroon waarbij het verschil tussen het hoogste gewicht dat 's nachts voorkomt en het laagste gewicht dat in de ochtend voorkomt 63 gram bedraagt. Het aantal bezoeken, de hoeveelheid wegingen, de uniformiteit en de duur van de bezoeken zijn afhankelijk van de plaats van de weegschalen in de stal. Gedurende een periode van 24 uur wordt de weegschaal die in het midden van de voeretage staat door 54 % van de hennen maar één keer bezocht. De gemiddelde lengte van bezoeken op deze plaats bedraagt 63 seconden. Geconcludeerd is dat automatische dierweegsystemen betrouwbare managementinformatie op kunnen leveren over het gemiddeld diergewicht en de uniformiteit van een groep dieren in een volièresysteem, waarbij het niet noodzakelijk is om de hennen individueel te herkennen. Uitgangspunt hierbij is dat de weegschalen in het midden van de voeretages geplaatst worden en dat zij alleen geactiveerd zijn als het licht in de stal aan is.

Uit de experimenten met EWACS en IPWS kan geconcludeerd worden, dat de gemeten dag-tot-dag variatie in de gegevens beïnvloed kan worden door de keuze van de meetmethode. De dag-tot-dag variatie kan op verschillende manieren gereduceerd worden. In de meeste gevallen betekent dit ook extra investeringen. De verwachte dag-tot-dag variatie voor het aantal getelde eieren per afdeling bedraagt 2.8 %. Het gemiddeld eigewicht, gemeten door weging van een stapel van 6 eiertrays, heeft een verwachte variatie van 3.1 %. De dag-tot-dag variatie voor het gemiddeld diergewicht, gemeten m.b.v. 4 weegschaaltjes die geplaatst worden in het midden van de voeretage en de uniformiteit van het diergewicht bedragen respectievelijk 1.1 % en 1.9 %. Als het aantal eieren per afdeling over vier opeenvolgende dagen gemiddeld wordt kan de variatiecoefficient gereduceerd worden tot 1 %. De variatiecoefficient voor het gemiddelde eigewicht kan tot 1.6 % gereduceerd worden als EWACS gebruikt wordt of als de gegevens over een paar opeenvolgende dagen worden gemiddeld. De variatiecoefficient voor het diergewicht en de uniformiteit kan gereduceerd worden door meer weegschalen per afdeling te gebruiken, door de gegevens over een paar opeenvolgende dagen te middelen, of door de gebruikte techniek in het automatisch weegsysteem te verbeteren.

4. Management hulpmiddelen

Voor de ondersteuning van de operationele bewaking van de drie kritische succesfactoren en om de dagelijkse verzamelde gegevens uit volièresystemen te analyseren, is een beslissingsondersteunend systeem (BOS) -LegVisie genaamd- ontwikkeld. Twee onderdelen van het BOS, de wiskundige formules die de dagelijkse input- en output variabelen van het produktieproces beschrijven en een expertsysteem (ES) voor het monitoren van het dagelijks produktieproces, zijn gedetailleerd beschreven.

De wiskundige formules beschrijven het dagelijks produktieproces met behulp van de input-variabelen voedselopname, wateropname, staltemperatuur en de output-variabelen legpercentage, eigewicht, tweede-soort eieren, grondeieren, cumulatieve uitval en uniformiteit. Deze formules zijn ook gebruikt om het inzicht in de dagelijkse variatie van de verschillende variabelen te vergroten. Literatuur en meetgegevens van 6 koppels uit een volièrehuisvestingssysteem zijn gebruikt voor de beschrijving van de wiskundige formules. Iedere formule is een functie van het aantal dagen in de legperiode.

De formules voor cumulatieve uitval, legpercentage, eigewicht, diergewicht en tweede-soort eieren beschrijven de individuele koppelgegevens goed ($0.72 < R^2_{adj} < 1.00$). De verklaarde variantie m.b.t. de formules voedselopname, wateropname, uniformiteit en het percentage tweede-soort eieren, is voor de afzonderlijke koppels in het algemeen lager ($0.33 < R^2_{adj} < 0.54$), hetgeen inhoudt dat de vorm van formules voor de afzonderlijke koppels verschillend kan zijn. Eigewicht, diergewicht, cumulatieve uitval en legpercentage vertonen, met een 'minimum' variatiecoefficient van 0.8-1.9 %, de laagste dag-tot-dag variatie, gevolgd door voedselopname, wateropname en uniformiteit met een variatiecoefficient van 2.8 - 3.6 %. Staltemperatuur, percentage tweede-soort eieren en percentage grondeieren vertonen, met een variatiecoefficient van 4.8 - 9.1%, de hoogste dag-tot-dag variatie. De conclusie is dat de ontwikkelde wiskundige formules gebruikt kunnen worden als norm of referentiewaarde bij het monitoren van het dagelijkse produktieproces. De 'gemiddelde' resultaten van de 6 koppels kunnen goed gebruikt worden als startwaarden voor nieuwe koppels hennen, maar de werkelijke produktieresultaten worden het dichtst benaderd als de wiskundige formules gedurende de legperiode regelmatig aangepast worden aan de koppel-specifieke omstandigheden. Het gevaar bestaat dan dat geleidelijke veranderingen in de werkelijke gegevens opgenomen worden in de norm en dus niet herkend worden als afwijkend.

Voor het opsporen van afwijkende produktieomstandigheden die gerelateerd zijn aan de drie kritische succesfactoren is een expertsysteem (ES) ontwikkeld. Het ES ondersteunt de pluimveehouder bij het monitoren van het dagelijkse produktieproces. Kennis van 5 experts is opgenomen in het ES. De kennisbank van het ES is opgebouwd is uit storingstabellen, welke zijn gebruikt om de kennis-representatie en het inferentie-mechanisme van het ES te standaardiseren. De detectie van afwijkende produktieomstandigheden is gebaseerd op kwantitatieve en kwalitatieve gegevens. Voedselopname, wateropname, staltemperatuur, legpercentage, eigewicht, diergewicht, uniformiteit, tweede-soort eieren, grondeieren en uitval zijn volgens de experts belangrijke kwantitatieve gegevens. Het ES vergelijkt de werkelijke produktieresultaten met de verwachte resultaten (normwaarde) en vergelijkt deze afwijkingen met combinaties van afwijkingen die bij bepaalde afwijkende produktieomstandigheden horen. Voor de gevoeligheidsanalyse en de validatie van het ES zijn gegevens van vier koppels hennen en vijf verschillende normen gebruikt. De validatie is beperkt gebleven tot de interne validatie en een pre-test die gebaseerd is op het gebruik van kwantitatieve gegevens. De keuze van de norm en de detectiegrens is sterk bepalend voor de sensitiviteit en de specificiteit van het ES. Er wordt voorgesteld om de 'gemiddelde' resultaten van de wiskundige formules te gebruiken als norm. De keuze van de detectiegrens hangt af van het gebruik van het ES. Als het ES wordt gebruikt voor een eerste 'screening' van de gegevens dan is het belangrijk om een hoge sensitiviteit te hebben. Als het ES de opsporingstaak van de pluimveehouder moet vervangen, dan moet zowel de sensitiviteit als de specificiteit hoog zijn. Bij deze laatste toepassing verwacht de pluimveehouder bij iedere melding dat er iets aan de hand is. Een compromis tussen een acceptabele sensitiviteit (63.6 %) en specificiteit (72.1) is bereikt bij het gebruik van een koppel-specifieke norm en een praktische detectiegrens.

Voorlopige berekeningen van de economische consequenties van afwijkende produktieomstandigheden tonen aan dat het netto verlies per ronde op kan lopen tot meer dan 20.000 gulden. Dit geeft het belang aan van een tijdige detectie van afwijkende produktieomstandigheden. Tevens geeft het aan welke verliesposten voorkomen kunnen worden door een BOS zoals LegVisie te gebruiken voor het bewaken van het dagelijkse produktieproces in het algemeen en het bewaken van de drie kritische succesfactoren: de beheersing van de voedselopname, de beheersing van de staltemperatuur, de tijdige detectie van ziektes in het bijzonder.

5. Conclusies

De volgende conclusies worden getrokken:

- Bij het gebruik van dagelijkse informatie in plaats van wekelijkse informatie moet het dagelijks management tenminste gericht zijn op de kritische succesfactoren: dagelijkse beheersing van de voedselopname, dagelijkse beheersing van de staltemperatuur en de tijdige detectie van ziektes.
- Managementhulpmiddelen moeten in de eerste plaats gericht zijn op de 'operationele bewaking' van de drie kritische succesfactoren.
- Het eierweeg- en eiertelsysteem (EWACS) is uitermate geschikt voor het tellen en wegen van eieren in experimentele situaties omdat het een zeer gedetailleerd beeld geeft van de eierproduktie.
- Automatische dierweegsystemen zonder individuele dierherkenning leveren betrouwbare informatie over het gemiddeld diergewicht en de uniformiteit in een volièrehuisvestingssyteem voor leghennen.
- Individuele herkenning van leghennen door middel van transponders is uitermate geschikt voor het bestuderen van en het verbeteren van de kwaliteit van automatische dierweegsystemen.
- De dag-tot-dag variatie in het aantal eieren, het eigewicht, het diergewicht en de uniformiteit is afhankelijk van de toegepaste meetmethode en de plaats en de tijd van de metingen.
- In een volièrehuisvestingssysteem is een afdeling de kleinste produktieeenheid waarvan

het zinvol is om produktiegegevens te verzamelen.

- De economische gevolgen van afwijkende produktieomstandigheden zijn dermate groot dat het het zinvol is om een beslissingsondersteunend systeem zoals LegVisie te gebruiken.
- De resultaten van het expertsysteem worden duidelijk verbeterd wanneer gebruik gemaakt wordt van zowel kwantitatieve als kwalitatieve gegevens.
- Niet lineaire wiskundige formules zijn uitermate geschikt voor het beschrijven van het produktieproces in volièrehuisvestingssystemen voor leghennen en om inzicht te krijgen in de 'normale' variatie die aanwezig is in het produktieproces.
- De resultaten van het expertsysteem worden duidelijk verbeterd als zowel kwantitatieve als kwalitatieve gegevens worden gebruikt.
- De opsporingsresultaten van het expertsysteem zijn afhankelijk van de keuze van een norm en een detectiegrens.
- Voor het bewaken van het dagelijkse produktieproces kan het expertsysteem goed gebruik van een norm die gebaseerd is op een wiskundige formule.
- Produktieomstandigheden die geklassificeerd worden als 'beginnend' veroorzaken nog teveel foute meldingen. Produktieomstandigheden die geklassificeerd kunnen worden als 'gevorderd' en 'ernstige' kunnen succesvol opgespoord worden m.b.v. het expertsysteem.

Curriculum Vitae

Cornelis Lokhorst is op 9 november 1961 te Maarsbergen, gemeente Maarn, geboren. Hij is opgegroeid op het veehouderijbedrijf van zijn ouders. In 1980 is het diploma Atheneum-B op het 'Revius Lyceum' te Doorn behaald. Van september 1980 tot en met januari 1986 is de studie 'Landbouwtechniek' aan de toenmalige Landbouw Hogeschool Wageningen gevolgd. Het hoofdvak Landbouwbedrijfsgebouwen is gecombineerd met de bijvakken Natuurkunde, Industriële Bedrijfskunde en Informatica. Van december 1985 tot mei 1986 heeft hij als toegevoegd onderzoeker op de vakgroep Landbouwtechniek van de Landbouw Hogeschool gewerkt. In die tijd is een prototype ontwikkeld van een informatiesysteem voor de pluimveehouderij, en er is een bijdrage geleverd aan de totstandkoming van het globale informatiemodel voor de pluimveehouderij.
Sinds 20 mei 1986 werkt hij als wetenschappelijk onderzoeker op de afdeling Bedrijfsmanagement van het IMAG-DLO. In de eerste vijf jaar is voornamelijk gewerkt aan de ontwikkeling van een groepshuisvestingssysteem voor zeugen. Vanaf 1991 werkt hij aan zijn promotieonderzoek dat betrekking heeft op de ondersteuning van de dagelijkse bedrijfsvoering bij volièrehuisvestingssystemen voor leghennen.