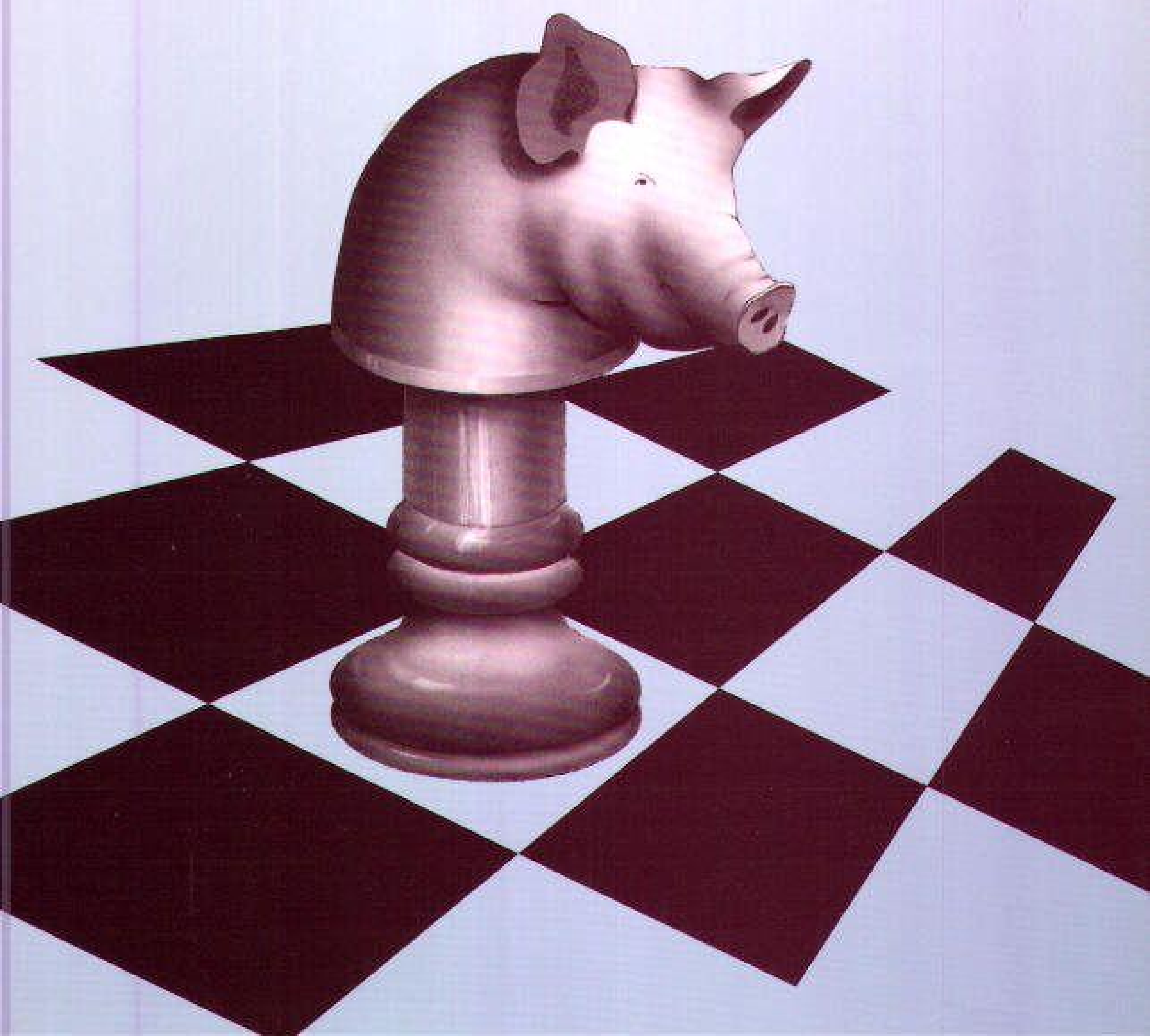
COMPUTERIZED MANAGEMENT SUPPORT FOR SWINE BREEDING FARMS

R.B.M. Huirne



STELLINGEN

1. Door rekening te houden met zowel de economische als de statistische relevantie van afwijkingen ten opzichte van de als gewenst aangemerkte situatie kunnen sterke en zwakke punten in het management van een individueel agrarisch bedrijf op een wetenschappelijk verantwoorde en praktisch toepasbare wijze worden opgespoord.

   Dit proefschrift

2. Bij het opstellen van een attentielijst van mogelijke afwijkingen in de bedrijfsresultaten dient een afweging te worden gemaakt tussen betrouwbaarheid en tijdigheid van de informatie.

   Dit proefschrift

3. Door koppeling van decision-support-systemen en expertsystemen is het bij de bepaling van de toekomstige winstgevendheid van individuele zeugen ter ondersteuning van het vervangingsbeleid mogelijk rekening te houden met zowel kwantitatieve als kwalitatieve eigenschappen van de zeug.

   Dit proefschrift

4. De wiskundige formulering van dynamische programmeringsmodellen suggereert ten onrechte dat de techniek als zodanig gecompliceerd is.

5. Het is in principe onmogelijk de validiteit van een computermodel aan te tonen, wel de invaliditeit.

   Gass, S.I. (1983). Decision-aiding models: validation, assessment, and related issues for policy analysis. *Operations Research*, 31 (4): 603-631

6. Die onderdelen van op commerciële schaal toegepaste management-informatiesystemen die verder gaan dan het registreren en rangschikken van gegevens zijn tot dusver inhoudelijk gezien vaak dermate arbitrair dat gebruik ervan, vanuit economisch oogpunt, aanzienlijke risico's met zich meebrengt.

7. Veterinaire bedrijfsbegeleiding kan alleen doelmatig zijn indien de betrokken dierenarts ook over voldoende bedrijfseconomische kennis beschikt, en daarmee een goed inzicht heeft in de economische betekenis van zijn handelen voor het bedrijf in kwestie.

8. Het doel van het uitvoeren van berekeningen met behulp van de computer dient niet het verkrijgen van getallen maar van inzicht te zijn.

Hamming, R.W. (1962). *Numerical methods for scientists and engineers*. New York: McGraw-Hill

9. De praktische waarde van informatiemodellen bij het ontwikkelen van management-informatiesystemen wordt sterk overschat.

10. De correlatie tussen risico-aversie en de waarde die aan informatie wordt toegekend is niet noodzakelijkerwijs positief omdat de beslissing om aanvullende informatie te verwerven zelf een riskante beslissing is.

Byerlee, D. and Anderson, J.R. (1982). Risk, utility and the value of information in farmer decision making. *Review of Marketing and Agricultural Economics*, 50 (3): 231-246

11. Wie kiest voor een actieve functie bij een universiteit moet, gezien het aangeboden salaris en carrièreperspectief, een grote mate van idealisme bezitten.

12. Het is verrassend dat in zaken die zo doorslaggevend zijn voor de reputatie van de wetenschapper, zoals het publiceren van wetenschappelijke artikelen, zij zich toevertrouwen aan de meningen van anonieme beoordelaars.

Maddox, J. (1990), hoofdredacteur van het Britse wetenschappelijke tijdschrift *Nature*. Lezing tijdens het veertigjarig bestaan van de Nederlandse organisatie voor Wetenschappelijk Onderzoek (NWO)

13. Zolang het openbaar vervoer niet wezenlijk is aangepast valt het in Nederland niet mee zonder auto mobiel te zijn.

14. De moderne landbouwer rekent momenteel niet alleen maar op zijn lei.

R.B.M. Huirne
Computerized management support for swine breeding farms
Wageningen, 18 december 1990

COMPUTERIZED MANAGEMENT SUPPORT FOR SWINE BREEDING FARMS

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COMPUTERIZED MANAGEMENT SUPPORT FOR SWINE BREEDING FARMS

Proefschrift

ter verkrijging van de graad van doctor
in de landbouw- en milieuwetenschappen
op gezag van de rector magnificus,
dr. H.C. van der Plas,
in het openbaar te verdedigen
op dinsdag 18 december 1990
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van de Landbouwuniversiteit te Wageningen.

Huirne, R.B.M. (1990). Computerized management support for swine breeding farms (Gecomputeriseerde managementondersteuning voor zeugenbedrijven). PhD Thesis, Department of Farm Management, Wageningen Agricultural University, Wageningen, The Netherlands.

The critical power . . .
tends to make an intellectual situation of which
the creative power can profitably avail itself
. . . to make the best ideas prevail.

From Matthew Arnold
The function of criticism
at the present time, 1864

VOORWOORD

Het in dit proefschrift beschreven onderzoek is uitgevoerd binnen de vakgroep Agrarische Bedrijfseconomie van de Landbouwuniversiteit te Wageningen. Vanaf deze plaats wil ik mijn dank uitspreken voor de bijdrage die door anderen hieraan is geleverd. Enkele personen wil ik graag met name noemen.

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CONTENTS

GENERAL INTRODUCTION

1. INTRODUCTION

Modern swine breeding has changed considerably during the last two decades. In the Netherlands, for instance, the total number of sows increased from 0.74 million in 1970 to 1.62 million in 1987, while the total number of swine breeding farms decreased from 46 thousand in 1970 to 17 thousand in 1987 (L.E.I.-C.B.S., 1989). The average number of sows per farm, therefore, increased significantly within these years from 16 to 95. The increase in size, however, was accompanied by decreasing income margins per unit of output (Baltussen *et al.*, 1988). Farmers' income, therefore, is increasingly sensitive to changes in productive farm performance. Moreover, today's swine breeding is confronted with many government regulations, changing tax laws, new emerging technologies and changing institutions. As a result, modern swine breeding imposes increasing demands on the farmer's management skills. Wrong management decisions may have a major (long-term) impact not only on overall operation of the farm itself, but also on the production chain of which the farm is one of the components. Thus, the need for accurate and consistent information for management support has become of paramount importance (King *et al.*, 1990).

2. SCOPE AND DEFINITION

Recent advances in computer hardware, software and telecommunications technology have increased the possibilities for effective computer-based support of farm management. The concept of management is nebulous and difficult to define, but can be described in terms of functions to be performed: planning, implementation and control. Planning involves developing a predetermined course of action. It represents goals and the activities to be implemented to achieve those goals. Control involves measuring farm performance and comparing it to standards or planned performance. The management functions can be considered as a cyclical process. Usually, planning precedes implementation which precedes control. Corrective actions with respect to deviations between performance and standards should first be planned, and then be implemented and controlled. Due to the complex nature of the planning and control function, management support should particularly be focused on these two functions (Davis and Olson, 1985).

The present study is directed towards computerized management support for swine breeding farms, focused on sow productivity and profitability. As part of the study, several modules of a management information system (MIS) for swine breeding farms have been developed. The MIS is primarily intended to support farm managers and other livestock specialists in analyzing the economic situation of individual sow-herds. The study is composed of three parts. In the first part, a basic description and definition of farm management and the concept of MIS are given to provide a basis for the second and third part of the study. The second part relates to the management control function and is concentrated on individual farm analysis, which can briefly be described as the first analysis of technical and economic records in order to identify and assess strong and weak elements in a farm's management. In the third part, more detailed attention is given to one of these elements: the sow replacement policy. The economically optimal sow replacement policy for swine breeding farms is studied considering - the quantitative and qualitative - variation in the performance of the sow and in the circumstances under which sows produce. This part mainly concerns the planning management function.

Data, knowledge and expertise from many sources are required to find solutions to problems in the above-mentioned areas. Most problems cannot be solved with more conventional problem-solving techniques alone (Engel *et al.*, 1990). Therefore two types of MIS applications have been considered: decision support systems (DSS) and expert systems (ES). A DSS can be described as an information system that supports the process of decision making. A DSS allows the decision maker to retrieve data, generate and test alternative solutions during the process of problem solving, and incorporates at least one mathematical model. An ES can be defined as a MIS using expert knowledge to attain high levels of performance in a narrow problem area, and thus can be considered as a modelling of the human reasoning process, making the same decisions as its human counterpart. This study should also give insight into the underlying question of whether the combination of DSS and ES is of any advantage in formulating and solving major problems in these areas.

3. OUTLINE OF THE THESIS

Scope and definition of farm management is discussed in Chapter 1, by giving attention to the management functions: planning, implementation and control. Chapter 1 also deals with the impact of recent advances in computer technology, and with the concept of MIS, including DSS and ES.

The economic framework for individual farm analysis is outlined in Chapter 2. In particular, the choice of appropriate standards for comparison, calculation of the economic impact of deviations from the standards, and determination of the relevance of deviations are described. Furthermore, a MIS named CHESS (Computerized Herd Evaluation Systems for Sows), designed to carry out individual farm analysis on the personal computer, is presented. CHESS consists of two sub-systems: DSS and ES. The process of knowledge acquisition, being a crucial step in developing ES, is also outlined.

Validation is an important stage in developing computerized systems, but its measurement is very difficult. ES are especially difficult to validate as they use symbolic problem solving techniques and heuristics to draw conclusions. Chapter 3 deals with the validation of CHESS. A sensitivity analysis of both sub-systems of CHESS (DSS and ES) is described, as well as a field test of CHESS as a whole.

Chapter 4, 5 and 6 deal with sow replacement optimization. In order to determine the economically optimal replacement policy, a stochastic dynamic programming model (DP-model) has been developed and incorporated as a module into the DSS sub-system of CHESS. The mathematical outline of the model is presented in Chapter 4. As realistic DP replacement models include a large number of state and decision variables, a major issue in this chapter is how to cope with the so-called curse of dimensionality. The curse of dimensionality determines strongly the efficiency of the DP-algorithm.

Zootechnical-economic aspects and results of the DP-model are described in Chapter 5. Influences of changes in production, reproduction and price parameters on the optimal policy are established. Furthermore, an economic index is calculated which is used as a culling guide for individual sows within a herd.

Culling decisions, however, are usually not based on productive and reproductive sow performance only, but also on more qualitative sow characteristics such as lameness and leg weakness, mothering characteristics and udder quality (Dijkhuizen *et al.*, 1989). These characteristics can hardly be included into the algorithmic DP-model, due to their qualitative nature. Therefore, an ES has been developed and integrated with the DP-model to account for such qualitative issues. The ES also adjusts the economic index, resulting in a more complete culling guide for individual sows. The ES is presented in Chapter 6. This chapter also considers the knowledge acquisition for, and validation of, the ES.

In the closing chapter, attention is focused on two general subjects of discussion: integrated decision support, and value of management information systems.

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CHAPTER 1

Basic concepts of computerized support for farm management decisions

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ABSTRACT

Good management is essential for efficient operation of any farm, but the concept of management is nebulous and difficult to define. Therefore, scope and definition of farm management is discussed first, by paying attention to the three major management functions: planning, implementation and control. Then, impact of recent advances in computer technology on farm management and concept of management information systems are described. Two potential applications of management information systems are presented: decision support systems and expert systems. The current challenge in building management information systems is to incorporate decision support systems and expert systems to create an effective tool for farm managers.

1. INTRODUCTION

Modern farms are generally attended with an increasing size and a narrowed income margin per unit output, defined as net return on labour and management as a percentage of gross returns (L.E.I.-C.B.S., 1988). Small differences in productive performance, therefore, result in an increasing difference in profit. As a result, modern farming imposes increasing demands on the farmer's management skills.

During the last decade, much has been published on farm management and farm management decisions with an increasing interest in decision support. Short and medium-term decisions are of particular interest, because recent advances in computer hardware, software, and telecommunications technology have increased the ability to provide effective computer based support (King and Harsh, 1987).

In this chapter, the concept of farm management is discussed by describing management and management decisions on farms. Furthermore, the concept of the management cycle is outlined, in which management is presented as a cyclical process. After discussing the changing role of computers in farm management, some major possibilities to support farm management decisions are presented, including management information systems, decision support systems, and expert systems. Suggestions are then made as to how these systems might be applied. Finally, based on basic concepts discussed in this chapter, the main issues to consider in building a system are formulated.

2. FARM MANAGEMENT DECISIONS

2.1. Scope and definition of management

Management, as described by Kay (1986), is the decision-making process in which limited resources are allocated to a number of production alternatives. This allocation of resources is organized and operated in such a way that goals and objectives are attained. Goals are considered to be more general statements and refer to the end point of all efforts of management; objectives are more specific and refer to activities planned to reach goals (Anthony and Dearden, 1980; Harsh *et al.*, 1981).

According to Simon (1960), the decision-making process can be divided into three major phases: (1) intelligence, (2) design, and (3) choice. Intelligence involves searching the environment for conditions asking for decisions. Data inputs are obtained, processed, and examined for clues that may identify problems or opportunities. In the second phase, design, possible courses of action are invented, developed, and analyzed. This involves processes for understanding the problem, for generating solutions and for testing solutions on feasibility. Choice, as the last phase of the decision-making process, involves selecting a particular course of action. There is a flow of activities from "intelligence" to "choice", but at any phase there may be a return to a previous phase. Although Simon's model does not go beyond the choice phase, other models of the decision-making process include implementation and feedback from results of the decision (Rubenstein and Haberstroh, 1965; Herbst, 1976; Sprague, 1986; Bosman, 1987).

To carry out different management activities within a farm operation successfully, the farm manager must have analytical experience and access to data in different areas of farm management (Boehlje and Eidman, 1984): (1) production, (2) marketing, and (3) finance. Production is the most basic area for the farm manager. Plans must be made and implemented with respect to the production system to be used for each enterprise (Boehlje and Eidman, 1984). Besides efficient production, marketing is an important area of management. To maximize income, farmers must take care to purchase inputs and sell products at prices that result in a profit (Bowring *et al.*, 1960). However, it is important to recognize that for many inputs and products the farmer operates as a pricetaker. Financing activities require management decisions on capital acquisition and capital use (Nelson *et al.*, 1973).

The decision-making process of the farmer takes place in an environment containing risk and uncertainty (Harsh *et al.*, 1981; Byerlee and Anderson, 1982; Casavant and Infanger, 1984). Risk is the situation where all possible outcomes are known for a given management decision and sufficient information is available to calculate statistical probabilities associated with each possible outcome. Uncertainty is the situation where all possible outcomes or probabilities are not known (Barnard and Nix, 1973; Casavant and Infanger, 1984; Sonka and Patrick, 1984; Kay, 1986). In most situations facing farmers true probabilities will not be known and, therefore, a pure risk situation will seldomly exist (Barnard and Nix, 1973; Anderson *et al.*, 1980). However, farm managers will often formulate subjective probabilities based on their judgement and experience. Subjective probabilities refer to the degree of belief or strength of conviction held by an individual about possible events or propositions (Savage, 1954; Lindley, 1971; Bessler, 1984). Different outcomes of decisions are possible since experience, background, and interpretations of available information of managers may result in different subjective probabilities (Lindley, 1971; Kay, 1986).

Risk and uncertainty make management a difficult and complex task. A farmer's success depends to a great extent on his ability to make good management decisions regarding these situations of risk and uncertainty.

2.2. Management functions and management cycle

Management can be discussed in terms of functions performed by the farm manager. The following three functions can be mentioned (Boehlje and Eidman, 1984; Kay, 1986): (1) planning, (2) implementation, and (3) control. These functions, which can be considered to be the three basic or primary functions of management, are described below.

Planning provides the mode of operation to accomplish the farm's goals and objectives (Koontz and O'Donnell, 1976). Essentially, planning involves selecting a particular strategy or course of action from amongst alternative courses of action with reference to organization of resources such as land, labour, and capital, with the objective of obtaining the greatest satisfaction of the farm's goals (Giles and Stansfield, 1980; Buckett, 1981; Boehlje and Eidman, 1984). Planning is the systematic design to direct future activities based on available knowledge. During the planning period, options for future activities are systematically considered, and compared with given situations, from which measures for optimal future organization are deduced (Zilahi-Szabo, 1975; Dalton, 1982). Thus, planning is deciding in advance what to do, how to accomplish each task, when to do each task, and who is responsible for completing each task (Barnard and Nix, 1973; Anderson *et al.*, 1980; Boehlje and Eidman, 1984).

Implementation is the execution of planned activities or, in other words, conversion of plans into reality (Giles and Stansfield, 1980). According to Kay (1986), implementing a plan is often a two-step procedure: (1) acquiring necessary resources, and (2) managing these resources over time as they are being used. The first step deals with acquisition of land, labour, and capital necessary to get the tasks done. The second step deals with organizing land, labour, and capital. This step involves organization of work to complete the tasks on schedule, and supervision and direction of the accomplishment of various tasks. Implementation involves not only physical labour to get the tasks done, but it also involves organizing and directing physical activities whether they be performed by farmers themselves or by other employees (Giles and Stansfield, 1980; Boehlje and Eidman, 1984).

Basic control processes involve measuring performance and comparing it to standards. Standards are criteria against which performance can be measured (Dalton, 1982; Castle *et al.* 1987). This process of comparing performance with standards can either be curative or preventive (Kempen, 1980). If it is curative, the actual performance of the farm is compared with actual standards, which represent the desired actual performance. A deviation can lead to corrective actions to direct actual performance. In the preventive case, the expected future performance is deduced from the actual performance. Subsequently, expected future performance is compared with future standards, which represent the desired future performance. Expected deviations may lead to corrective actions to direct future development of the farm (Figure 1). Standards are derived from goals and objectives that have been specified by the farm manager. Standards may be measured in physical terms, such as piglets weaned per litter, or in financial terms, such as net return to labour and management (Giles and Stansfield, 1980; Boehlje and Eidman, 1984).

Because of the many uncertainties in agricultural production, deviations are always present. If their type and magnitude can be identified at an early stage, it is possible to keep plan and desired results within a predefined acceptable range (Kay, 1986). A further analysis of deviations should indicate to the manager what the causal problem might be (Boehlje and Eidman, 1984). Control implies not just investigation of progress of some change in the farm operation, but also regular checks on the whole system, even if it has been operated successfully for many years (Barnard and Nix, 1973).

Correction of deviations between performance and standards takes place in the next management cycle. Corrective actions should first be planned, and then be implemented. In the control phase, it is important to check whether previous corrective actions had the desired effect on performance.

Relations between planning, implementation, and control are illustrated in Figure 2.

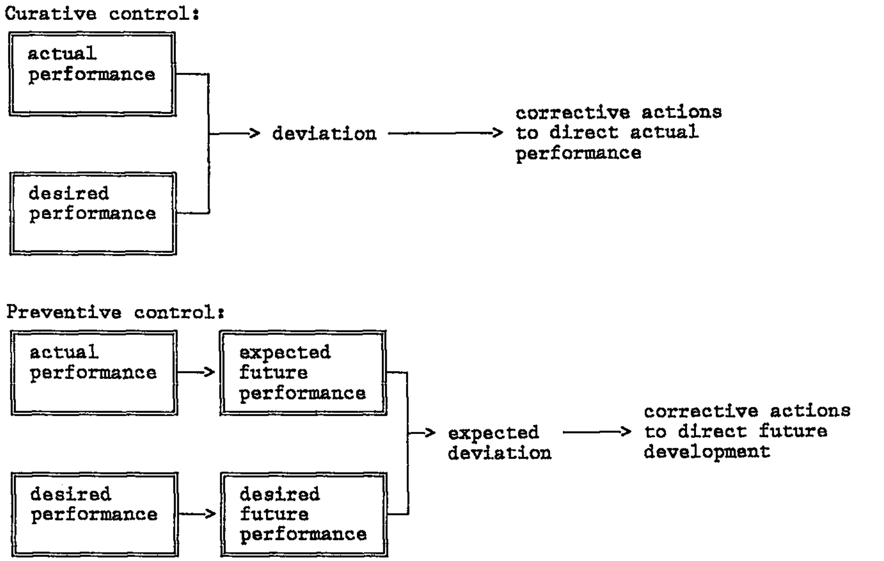

Figure 1. Difference between curative and preventive control (Kempen, 1980)

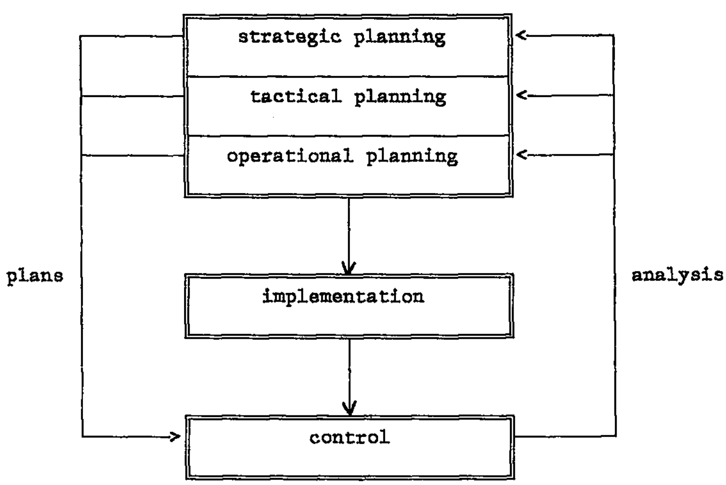

Figure 2. The management cycle

Figure 2 demonstrates the cyclical nature of the management process: the management cycle. Depending on the planning horizon, strategic, tactical, and operational planning may be considered. Strategic planning results in a long term plan (years), which includes the plan for farm structure. Tactical or medium term planning (year, season) is carried out inside the scope set by strategic planning. It involves planning to obtain optimal results within the given or proposed the farm structure. During operational or short term planning (weeks), a more detailed plan is produced from the tactical plans, depending on the actual situation on the farm, and related to implementation of the chosen production process. This is called the hierarchy of planning (Hirshfield, 1983). As control is the process of assuring that specific tasks are carried out effectively and efficiently (Anthony, 1965), it concerns possible deviations between actual results and operational plans. Control also involves identification of both strong and weak aspects of the farm. Results of control may lead to new strategic, tactical and operational plans.

3. SUPPORT OF FARM MANAGEMENT DECISIONS

3.1. The computer, an emerging tool for the farm manager

The role of information technology in our society is changing rapidly. Until recently the need to minimize the costs of data entry, processing, and storage have been the dominant issues. Largely as a result of introduction of personal computers, computer technology is now more powerful, accessible and affordable. Because of a declining price-performance ratio, the personal computer is becoming an interesting tool on the farm (Pugh, 1979; Berg, 1985). At the same time, tasks for which computers can be used are also evolving. Application of computers is reaching into all aspects of management and is no longer limited to data analysis. Economic calculations at the farm level will become possible because they can be done faster, adjusted to the individual farm, and carried out without errors (Kirby and Rehman, 1983). In a number of complex problem solving activities that require apparently unique human skills, boundaries between roles of people and machines are continually being redefined. Computers are becoming essential support tools in many of these activities. These advances in electronics will increase the amount of (farm specific) data available, providing a basis for farm or enterprise control and evaluation (Westlake, 1980; Sonka, 1983; Casavant and Infanger, 1984; Schiefer, 1985).

The need to make decisions generates a demand for data. Because decision makers rarely use raw data, there are intervening acts of interpretation and calculation, which transfer data into information by placing them in a specific problem context to give meaning to a particular decision (McDonough, 1963; Eisgruber, 1978; Harsh, 1978). Although the terms "information" and "data" are frequently used interchangeably, information is generally defined as data that are meaningful to the recipient. Data items are, therefore, the raw material for producing information (Davis and Olson, 1985). Distinction between data and information is useful in setting up a decision system and identifying what data to collect. If a piece of data cannot be processed into information and thus be useful in improving a decision, it should not be part of the system (Boehlje and Eidman, 1984). It is important to recognize that information provided by computers must be relevant to basic managerial needs (Connor and Vincent, 1970; Zani, 1970). Furthermore, if the costs of collecting and processing data into information exceed the economic benefits such data should not be part of the system (Eisgruber, 1978; Boehlje and Eidman, 1984).

3.2. Management information systems

3.2.1. Scope and definition

Information processing is an important activity for the farm manager. Much time has to be spent on recording and absorbing information. In the 1970s, the lack of suitable hardware and software was a limiting factor on the design of computer based information systems (Keen and Scott Morton, 1978). The current challenge in information processing is to use the capabilities of computers to support managerial activities and decision making.

Dannenbring and Starr (1981) classify the wide variety of computer systems that encompass collection, maintenance, and use of information for organizational purposes as management information systems (MIS). Davis and Olson (1985) define a management information system more precisely as an integrated, user-machine system for providing information to support operations, management, and decision-making functions in an organization. The system utilizes computer hardware and software; manual procedures; models for analysis, planning, and control and decision making; and a database.

According to Davis and Olson (1985), there are four important elements in the definition of a MIS: (1) user-machine system, (2) concept of an integrated system, (3) need for a database, and (4) role of models.

The concept of a user-machine system implies that some tasks are best performed by humans, while others are best carried out by machine (computer). The user of a MIS is any person responsible for entering input data, constructing the system, or utilizing information produced by the system. For many problems, the user and computer form a combined system with results obtained through a set of interactions between computer and user.

A MIS provides the basis for integration of organizational information processing. Individual applications within information systems are developed for and by diverse sets of users. If there are no integrating processes and mechanisms, individual applications may be inconsistent and incompatible. The same data items may be specified differently and may not be compatible across applications. Information system integration is achieved by making an overall information system plan, and also through standards, guidelines, and procedures set by the MIS function. The fact that a MIS is an integrated system requires that the parts fit into an overall design.

The underlying concept of a database is that data need to be managed in order to be available for processing and to have appropriate quality. Such data management includes both software and organizational aspects.

It is usually insufficient for a human recipient to receive only raw data or even summarized data. As discussed before, data usually need to be processed and presented in such a way that the result is directed toward the decision to be made. In a comprehensive information system, the decision maker has a set of general models available that can be applied to many analysis and decision situations plus a set of very specific models for unique decisions. Models are generally most effective when the manager can use interactive dialogue to build a plan or to iterate through several (decision) choices under different conditions. Alter (1980) mentioned several important classes of models, which include (1) models that calculate the consequences of particular actions on the basis of accounting definitions. They typically generate estimations of income, balance sheets etc., based on variations in input value, (2) models that estimate the consequences of actions on the basis of models that represent some non-definitional characteristics of the system such as probabilities of occurrence. They include simulation models that contain elements beyond accounting definitions, and (3) models that provide guidelines for action by generating the optimal solution consistent with a series of constraints. They are used for repetitive decisions that can be described mathematically and where a specific objective, such as minimizing costs, is the goal.

3.2.2. Current developments

In the Netherlands, current systems for providing information to farmers do not go far beyond the traditional recordkeeping approach. These are essentially accounting systems for technical and economic farm data, including bookkeeping. They register data on production levels, quantities and prices of inputs and products, and on costs and returns of the farm and enterprises as well. Although often called MIS, these systems do not fit the above definition, because: (1) there is not a concept of an integrated system, and (2) they do not use models. Moreover, most of the systems available in practice tend to be inconsistent and incompatible, because data items are specified in a different way.

The current challenge in building MIS is to develop a framework for an integrated information system, which different systems or subsystems can fit into. In the Netherlands, the construction of such a framework, called an information model, was started in 1984 by the Ministry of Agriculture and Fisheries. Information models are constructed for several types of farming, including dairy cattle, pigs, arable farming and horticulture. They consist of a process model and a data model. The process model describes the activities or processes on the farm and the information exchange between these processes and the external environment. The data model describes the facts or data which are relevant to the farmer's decision-making. Processes and data are described independently of their use, resulting in standardized processes, data, and calculation rules (Folkerts, 1988). The process model can be used for designing models, the data model for databases. An important advantage of standardized data is using the same data in several applications. Furthermore, standardized data offer a possibility to automate data exchange between applications. This eliminates the additional work of multiple data entry and the risk of inconsistencies in databases.

For swine breeding farms, initial results were published by Verheijden *et al.* (1985), for horticultural farms by Beers *et al.* (1986), and for dairy farms by Brand *et al.* (1986). They all found that there is especially a need for systems supporting operational and tactical management decisions. Systems which will be developed in future in this field should, of course, fit into the framework of the information model.

3.3. Potential applications of management information systems

An important element in the definition of MIS is management of data. The information model also plays an important role in this context, because it contains unique definitions of processes, data and calculation rules. To operate their business, farm managers need data for information processing to carry out the functions of the management cycle: planning, implementation, and control (Figure 2).

It is not necessary that planning activities occur on a periodic, regular cycle, although some planning may be scheduled into a yearly planning and budgeting cycle. Data requirements for planning generally include processed, summarized data from a variety of sources. Beside the need for internal data, including the analysis results from previous control phases, planning also needs a considerable amount of external data. External data are needed on (Harrington and Schapper, 1979; Davis and Olson, 1985; Verheijden *et al.*, 1985): (1) outlook for the economy in the farms current and prospective areas of activity, (2) current and prospective environment of the farm, (3) goals and objectives of the farmer, and (4) production and financial possibilities and developments of the farm. These data include some objective observations, but much is based on subjective judgement. Although much of the data cannot be collected on a regular basis, and much of it cannot be specified completely in advance, it can provide substantial aid to the planning process.

For implementation, the second function of farm management, data are needed to carry out operations effectively and efficiently. Operational decisions and the resulting actions usually cover short-term periods. Data needed for implementation are primarily internal data generated from transactions and operations. They may include tactical and strategic farm and enterprise plans, as well as data on crop and animal production, inventories, durable means of production, and liquidity. These data items are generally relatively current (Davis and Olson, 1985; Verheijden *et al.*, 1985).

With respect to the control function, the third function of farm management, it is essential that the farm manager obtains detailed data on the cost and returns in each enterprise, labour and machinery utilization schedules, and appropriate production efficiency ratios to compare farm performance to developed standards. Thus control involves the traditional farm management recordkeeping, data on the environment of the farm, tactical and strategic farm and enterprise plans, data on planned performance (standards), and data on possible decisions or courses of action (Harrington and Schapper, 1979; Davis and Olson, 1985; Verheijden *et al.*, 1985). Much of these performance data are inadequate for control purposes because (Boehlje and Eidman, 1984): (1) many farmers measure performance only on an annual basis, such that an entire production period elapses before actual performance is compared with standards, and (2) the performance variables being monitored often provide little indication of potential problems, because these data provide only aggregated data on performance for the typical multi-enterprise farm.

So, both internal and external sources for obtaining data are needed. Data on past, present, and expected performance of the farm and its operating environment are obtained from internal sources. Data on capital, labour, and land markets, production price levels, government tax policies, environmental regulations, new technology, and weather forecasts must be obtained from external sources. These include literature, mass media, farm organizations, agribusiness firms, and the national weather service (Harsh *et al.*, 1981).

3.4. Decision support systems and expert systems

MIS is a broad term for a variety of computer systems. Two important types of systems are discussed below: (1) decision support systems (DSS), and (2) expert systems (ES).

A DSS is a MIS application that supports the process of making decisions (Davis and Olson, 1985; Goslar *et al.*, 1986). According to Alter (1976) and Keen (1986), DSS support rather than replace managers responsible for making and implementing decisions. DSS allow the decision maker to retrieve data and test alternative solutions during the process of problem solving, and incorporate a variety of models. DSS, therefore, imply the use of computers to improve the effectiveness of decision making (Keen and Scott Morton, 1978; Huber, 1982).

Highly repetitive decisions can frequently benefit from DSS. If the basic decision process is the same each time, a model can be made to fit the process, even for a single decision maker. Potential benefits of such systems are faster decision making, improved consistency and accuracy, and improved methods for analyzing and solving problems (Alter, 1980; Keen, 1986). At the other extreme, non-repetitive, unique decisions require decision support of a very different nature. Primary requirement of systems to support unique decisions is flexible access to a database and other forms of information such as external databanks (Davis and Olson, 1985).

The Simon model of decision making (Simon, 1960), which has been presented before, includes three phases: (1) intelligence, (2) design, and (3) choice. Each of these three phases can be supported by a DSS. The intelligence phase of the decision-making process consists of problem finding activities. Analysis and choice cannot proceed until the problem has been identified and formulated. The intelligence phase, therefore, consists of searching or scanning the internal and external environment for conditions which suggest an opportunity or a problem (Davis and Olson, 1985). Existence of an opportunity or a problem initiates the design and choice phases of decision making. The design phase involves inventing, developing, and analyzing possible courses of action. Support of the design phase should provide for iterative procedures in considering alternatives. Support can be divided into three steps (Davis and Olson, 1985): (1) support in understanding the problem, (2) support for generating solutions, and (3) support for testing the feasibility of solutions. The choice phase requires application of a choice procedure. Although a DSS does not make a choice, optimization models and simulation models can be used to rank alternatives and otherwise apply procedures to support the choice of the decision maker (Davis and Olson, 1985).

ES are a different class of MIS applications. An ES, as defined by Waterman (1986), is a computer program using expert knowledge to attain high levels of performance in a narrow problem area. It normally requires many years of special education, training and experience for an human expert to achieve a high level of performance in a specific task (Brachman *et al.*, 1983). Factual and inferential knowledge of an expert, which may include heuristics and vague knowledge, are stored in the ES. ES typically represent knowledge symbolically, and examine and explain their reasoning process (Waterman and Hayes-Roth, 1983; Fordyce *et al.*, 1987). Thus, because an ES is a modelling of the human reasoning process, it gives the same advice or makes the same decisions as a human expert. An ES asks questions and provides answers based on those questions. At each state of the reasoning process, an ES should be able to give information about what assumptions it is following, why it has chosen the method it is pursuing, to what conclusions it has already come, and how it has reached these conclusions (Kastner and Hong, 1984). It should give advice even when data are incomplete or uncertain. In general, ES are focused on improving problem solving (Pfeifer and Lüthi, 1987). Using an ES, a non-expert can achieve performance comparable to an expert in that particular problem domain (Nau, 1983).

Most existing DSS and ES are used as independent systems. DSS operate as support devices to decision makers while ES operate as independent expert consultation systems. An interesting question underlying this situation is how to integrate ES into existing or evolving DSS. In certain problem areas the integration of DSS and ES may have distinct advantages to yield synergetic results (Fordyce and Sullivan, 1986; Turban and Watkins, 1986[a]; Pfeifer and Lüthi, 1987). These benefits of DSS-ES combination can be realized in several ways: DSS contribution, ES contribution, and the synergetic resulting from the DSS-ES integration. Results of DSS and ES should be reconciled and evaluated, with the expectation that a joint effort produces better results than DSS and ES separately. The objective of the integration is to take advantage of strong points of both DSS and ES in order to create more powerful and useful systems. Turban and Watkins (1986[b]) present two frameworks for integration: (1) ES integration into conventional DSS components, and (2) ES as an additional component of DSS. The first type of integration relates to ES integration into one or more of the three basic DSS components (Sprague and Carlson, 1982): the database, the modelbase, and the user-interface. The second type considers ES as a fourth component in the DSS, where ES output can be used as DSS input, or *vice versa.*

4. DISCUSSION AND OUTLOOK

In the previous sections, three functions of farm management have been discussed: planning, implementation, and control. During the control phase performance is compared with standards. When there are deviations between performance and standards corrective actions should be taken. Some authors consider these corrective actions as a part of the control function (for example, see Boehlje and Eidman, 1984). In this chapter, however, the concept of the management cycle is described, in which it can be considered that the corrective actions resulting from the control function form the start of a new management cycle (planning-implementation-control). As described before, because of the many sources of uncertainty in agricultural production, deviations are always present. The question has to be answered what level of deviation should be tolerated and what is unacceptable. Further research is also needed to develop a method for translating these intolerable deviations into corrective actions that must be taken to improve farm or enterprise performances. The latter may include highlighting strengths, to be exploited, and weaknesses, to be eliminated, in farm or enterprise management and organization.

In this chapter, the management information system (MIS) definition of Davis and Olson (1985) has been used. According to this definition, MIS include models for analysis and decision support, and as a consequence, DSS and ES as specific MIS-applications. A major component in this view is the transformation of data into information to give meaning to a particular decision by placing data items in a specific problem context. Support for this view can be found in the literature, including Ives *et al.* (1980), Dannenbring and Starr (1981) and Hurtubise (1984), but other definitions for MIS are also used, in which MIS are usually defined as systems for recordkeeping or database management only (Keen and Scott Morton, 1978; Sprague, 1986).

MIS take many forms. The main issues to consider in developing a MIS can be formulated. A MIS can be developed to provide information for one or more farm management functions (planning, implementation, and control) in one or more areas of farm management (production, marketing, and finance). Depending on the choices made concerning previous issue, it must be identified what data to collect for processing into information. Since farm management takes place under continual changing conditions, it is important for MIS-users that they can build their subjective probabilities into the system, concerning situations of risk and uncertainty. In the case of DSS, it must be pointed out what phase of the decision-making process (intelligence, design, or choice) should be supported.

Expert systems (ES) can make decision support systems (DSS) a more powerful and useful tool in supporting the decision-making process. However, although DSS-ES-integration can yield synergetic results in certain problem domains, it should not be concluded that most future systems will be integrated. On the contrary, most DSS (especially small ones for personal use) will operate as independent systems, which are completely unrelated to any ES. Similarly, many ES will remain independent, advising users on a specific problem domain. For supporting farm management decisions, however, some types of DSS-ES-integration may be of special interest. Farm managers and their advisors, who generally are not experienced computer users and do not know formal computer languages, may have problems with using the computer. ES integration with the user-interface of the DSS can solve these communication problems. One of the most interesting applications in this context is the natural language interface as front-end. Other areas of integration with the user-interface include ES that can add the explanation capability to the DSS to allow the user to follow the reasoning behind certain recommendations. For supporting farm management decisions, it may also be worthwhile to add ES as a separate fourth component in the DSS. In many cases concerning agricultural production, DSS provide results of a computerized quantitative analysis, which are usually evaluated by one or more experts. In these situations it would make sense to transfer the DSS output to an ES which would perform the same function as an expert. This type of DSS-ES-integration becomes practical whenever it is cheaper and/or faster to do so, especially if the quality of the advice is also superior. Research is underway to provide such a system for swine breeding farms.

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CHAPTER 2

Computerized analysis of individual sow-herd performance

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ABSTRACT

Managing commercial livestock farms is becoming more difficult and important. Individual farm analysis can help farmers to become aware of the strong and weak elements in their management. In this chapter a systematic and objective methodology for such an approach has been developed and discussed. In this approach four stages are being considered for both trend and comparative analysis: tracing deviations, weighting deviations, further analysis of deviations, and evaluation of individual farm performance.

Based on this approach a personal computer system, named CHESS, has been developed to analyze the economic and technical records of individual swine breeding herds. The system consists of both one decision support system and three expert systems, designed in a modular manner. The decision support system identifies and assesses the importance of relevant deviations between performance and standards. Its output is used in the expert systems that try to find the strengths and weaknesses by combining and evaluating the previously identified deviations. A field test to validate the system as a whole resulted in a test agreement between CHESS and human experts of about 60%. The percent mis-classification error turned out to be 4% only. So, CHESS shows to be a promising tool in performing - theoretically sounded but widely accessible - individual farm analyses.

1. INTRODUCTION

Commercial swine farming is generally characterized by extended herd sizes and narrowed income margins (L.E.I.-C.B.S., 1988). Minor differences in productive performance have an increasing impact on economic results. It is, therefore, important that farm managers are aware of the strong and weak elements in their farm management (Huirne, 1990). The importance of the control function of farm management has been emphasized in the literature (see for instance: Anthony, 1970; Boehlje and Eidman, 1984; Davis and Olson, 1985).

The technique of individual farm analysis can be used to trace such strong and weak elements. The technical and economic records of individual farms are analyzed and signals for the future are provided by highlighting current strengths to be exploited, and weaknesses to be eliminated or improved. A systematic methodology of individual farm analysis, however, is not available in the literature. In practice, it is performed pragmatically, depending heavily on the person who carries it out. Therefore, research was initiated to develop a well founded systematic and objective approach for individual farm analysis. The basic concepts of this approach are presented in the first section of the chapter. In particular, the choice of appropriate standards for comparison, calculation of the economic impact of deviations from the standards, and determination of the relevance of traced deviations are described.

Theoretically, individual farm analysis can be performed manually. However, this is tedious and time consuming and, therefore, obvious to be built into a computer model. Such a model works fast and can be used by different people, including those who lack the skills required to perform individual farm analysis manually. In the second section of the chapter a system is presented, named CHESS (Computerized Herd Evaluation System for Sows), which uses the technique of individual farm analysis. The system uses records of individual farms and of other (groups of) farms, and has the ability to interface with both external simulation and optimization models for data exchange, and with information systems for automated data input. As a supporting technique for the farm manager, it can be used for early tracing of problems and for determining the maximum amount that could be spent in exploiting or improving farm performance. In describing CHESS, special attention is given to the integration of its two major subsystems: the decision support system (DSS) and the expert systems (ES). The process of knowledge acquisition for the ES of CHESS, which is a crucial and difficult step in developing expert systems, is outlined in the third section.

Validation is an important stage in developing computerized systems, which may be described as comparing the computer system with the observed world (Gilchrist, 1984). Measurement of the validity of any system, however, is a difficult issue. Especially ES are difficult to validate as they use symbolic problem solving techniques and heuristics to produce conclusions. This may partially explain why no validation methods for ES could be found in the literature. In the fourth section of the chapter, the validation procedure used for CHESS and its major results are presented and discussed.

2. A CONCEPTUAL APPROACH FOR INDIVIDUAL FARM ANALYSIS

2.1. Basic concepts

Farm records primarily reflect the historical performance on a farm. When analyzed carefully, however, they also provide signals for the future by highlighting current strengths to be exploited, and weaknesses to be eliminated or improved. False signals should be avoided and real problems not overlooked. As both strengths and weaknesses can be temporary, appropriate analyses involve detailed examination of all issues contributing to a farm's success or failure. Potential underlying causes of changes should be examined as well. To improve future farm performance, reasonable predictions of performance repeatability should be made (Buckett, 1981). Hence, individual farm analysis requires a systematic approach.

Individual farm analysis, defined within the framework of this chapter, is the comparison of the performance of an individual farm with a set of standards in order to identify strong and weak elements in farm management, and to determine the economic impact of these elements on current and future performance. In this context, farm performance and performance standards are synonymous with performance indicators and performance goals, respectively.

Individual farm analysis has two different facets depending on the type of standards employed (Harsh *et al.*, 1981). First, standards for comparison can be derived from the farm itself. This type of analysis is commonly called internal farm analysis. If internal farm analysis is done on a multi-year basis it is generally referred to as "trend analysis". The objective of trend analysis is to evaluate the development of the farm over time. Second, standards may be derived from another (similar) farm or a group of (similar) farms. This type of analysis, commonly called external farm analysis or "comparative analysis", is carried out primarily to determine the relative position of the farm. Besides trend analysis and comparative analysis, the conceptual model also includes a combination of these two types of analysis: "comparative trend analysis". The objective of comparative trend analysis is to evaluate differences between the development of the farm and the average development of a group of (similar) farms.

Each of these three types of internal and external farm analyses can be divided into four interrelated stages: (1) tracing deviations, (2) weighting deviations, (3) further analysis of deviations, and (4) evaluating individual farm performance. These four stages are summarized in Figure 1.

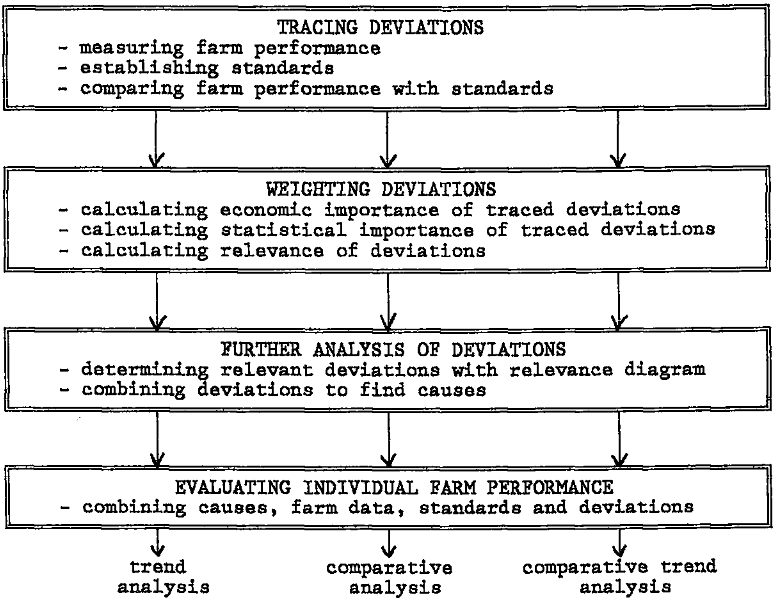

Figure 1. Stages in individual farm analysis

Most quantitative literature concerning the subject of individual farm analysis, including Barnard and Nix (1973), Koontz and O'Donnell (1976), Anthony and Dearden (1980), Harsh *et al.* (1981), Boehlje and Eidman (1984) and Castle *et al.* (1987), has focused on the tracing of deviations. Questions concerning the economic ranking of important problems or at what level deviations should be considered relevant are not considered. To answer these and other questions, a more comprehensive and quantitative approach to individual farm analysis, incorporating stages 1 through 4 has been developed.

2.2. Tracing deviations

Tracing deviations involves three major aspects: (1) measuring farm performance, (2) establishing standards, and (3) comparing farm performance with standards (Figure 1).

2.2.1. Measuring farm performance

An important issue in the measurement of farm performance is data reliability. To be reliable, data must be accurate and consistent. This may require objective measurement systems, such as scales for weighing livestock (Boehlje and Eidman, 1984). Quarterly technical and economic data of the pig-producing enterprise of an individual farm are used for performance monitoring. These data are usually provided by an information system used on the farm.

2.2.2. *Establishing standards*

The second aspect of tracing deviations concerns the establishment of performance standards. Kay (1986) identifies several types of standards that can be used to analyze performance parameters. If controlling and monitoring are the primary purposes of a whole farm analysis, budget goals and objectives are appropriate standards for comparison. When results fall short of budget objectives, an area requiring managerial effort is identified. Historical data of the farm itself is another type of standard. With this type of standard trends toward improvement or decline in performance are identified. Historical records are less useful for determining minimum standards, however. Parameter values of another farm or group of farms are yet another type of standards that may be used for comparison. Standard farms should be similar with respect to demographic factors, such as farm type, size and location.

The concepts of the historical (internal) and comparative (external) cohort standards are utilized in our conceptual model so as to accommodate the three types of analyses, which have been introduced in the previous section. First, a statistical forecasting technique is used for trend analysis using historical records. Historical farm data with a time-interval of three months up to three years are analyzed in a linear trend model. Use of this model assumes that during such a relatively short time-period, farm performance variables approximate to a linear development with respect to time. The forecasting model has the following form:

$$y_{tj} = a_j + b_j t + e_{tj} \tag{1}$$

where:

- y_{tj} = realized values (observations) for performance variable j at time-period t;
- a_j = intercept of performance variable j, which equals the expectation of y_{0j};
- b_j = slope of performance variable j relative to increments of time t;
- e_{tj} = sequence of unexplained independent random quantities of performance variable j.

Standards in this approach are the forecasts of the model for the time-period $t = T$. Therefore, $1 \leq t \leq T\text{-}1$ in the linear trend model. The least squares method is used to estimate the parameters a and b, such that the model shows a good fit to the data and can be extrapolated to obtain a forecast for time-period $t = T$. The forecast of the value y_j of a certain performance variable j at the actual time-period T (y_{Tj}) is simply obtained by substituting time T in the equation. Forecasts and thus internal standards (IS_j) are calculated as:

$$IS_j = \hat{y}_{Tj} = \hat{a}_j + \hat{b}_j T \tag{2}$$

where:

$\hat{y}_{Tj}$ = forecast or standard of performance variable j at time T;
$\hat{a}_j$, $\hat{b}_j$ = estimated parameters for performance variable j.

This forecasting procedure is carried out for all historical performance variables j of each individual sow herd.

The second type of standards used is derived from the actual performance of a group of similar farms over the same time-period ($ESmean_j$ = external standard mean for variable j across the comparison farms). These standards equal average performance of the group, and are used for comparative analysis.

The third type of standards is used for comparative trend analysis, and is derived from the development of performance of similar farms over time. The least squares method is used to estimate the individual farm parameters k_j and l_j of the linear trend model

$$y_{tj} = k_j + l_j t + e_{tj} \tag{3}$$

using historical farm performance with a time-interval of three months up to three previous years including time-period T ($1 \leq t \leq T$). Note that k_j and $l_j t$ are equivalent to a_j and $b_j t$ in equation (1) respectively. Given the estimated values for the linear trend parameters for the average development of the group of similar farms over exactly the same time-periods (estimated intercept $\hat{m}_j$, and slope $\hat{n}_j$ of the linear trend model:

$$y_{tj} = m_j + n_j t + e_{tj} \qquad (4))$$

external standards ($EStrend_j$) for the actual time-period T are calculated as:

$$EStrend_j = \hat{y}_{Tj} = \hat{k}_j + \hat{n}_j T \tag{5}$$

where:

$\hat{y}_{Tj}$ = external standard of performance variable j at time T;
$\hat{k}_j$ = estimated intercept of farm performance variable j;
$\hat{n}_j$ = estimated slope of performance variable j in the group of similar farms.

2.2.3. Comparing farm performance with standards

The third aspect of tracing deviations involves comparing farm performance with standards. Depending upon the standards used, three sorts of comparisons are carried out: (1) actual farm performance compared with predictions based on historical data, (2) actual farm performance compared with average performance of similar farms over the same time-period, and (3) historical development of farm performance compared with the average development of performance of a group of similar farms during the same time-periods. The third comparison is between the estimated trend value of performance variable j at time-period t = T ($\hat{y}_{Tj} = \hat{k}_j + \hat{l}_j T$) of the farm and the standard at time-period t = T ($EStrend_j = \hat{y}_{Tj} = \hat{k}_j + \hat{n}_j T$), which reflects the difference in estimated slopes. The deviations are assessed in their original dimensions, such as litter size in number of pigs born alive, piglet mortality in percentage of litter size, and feed price in Dutch guilders (Dfl.) per 100 kg.

Because of the many uncertainties in agricultural production, deviations between performance and standards always exist. The question is at what level should deviations be considered relevant. In answering that question, deviations are weighted in the conceptual model taking into account two factors: (1) economic importance, and (2) statistical importance of the deviation. Both of these factors are considered in detail below.

2.3. Weighting deviations

2.3.1. Economic importance

The second stage of individual farm analysis firstly involves the economic weighting of traced performance deviations. Deviations between actual performance and standards will differ and the economic importance of one unit of deviation will vary between variables, depending on their impact on total economic farm performance. Thus the economic importance of deviations differs between farms and should be calculated for each farm separately. Because the relationships between deviations and economic importance may be non-linear for some variables, the economic importance is not calculated per unit deviation but for the actual magnitude of deviation.

As stated above, all deviations are initially assessed in their original dimensions. By calculating the economic importance of deviations, all deviations are converted to the same units and, therefore, comparisons can be made. Because information systems used on swine breeding farms are usually restricted to the individual pig producing enterprise, the most aggregated variable in the conceptual model is the gross returns minus feed costs per sow per year. This figure accounts for all enterprise returns and for the major variable costs, being feed costs of sows and piglets. Fixed costs are not taken into account in this enterprise approach. In calculating the economic values of variables the model adheres to an analysis scheme (see Figure 2). Gross returns minus feed costs per sow per year are broken down into feed costs per sow per year and gross returns per sow per year. The feed costs are then divided into price and amount components for sow feed costs and pig feed costs. The gross returns are divided into gross returns of pigs per sow per year, which are primarily determined by the number of feeder pigs sold per sow per year, and the gross returns of sows per sow per year. The number of feeder pigs sold per sow per year is an important variable in analyzing individual farm performance, because many important technical performance indicators are combined in it, such as litters per sow per year and litter size.

The economic importance of deviations is calculated as follows. First, performance variables of the sow herd to be analyzed are introduced into the analysis scheme, which results in a value for gross returns minus feed costs per sow per year. Then, each performance variable is consecutively replaced by the corresponding standard, which gives a deviation in gross returns minus feed costs per sow per year. In other words, the traced deviations are consecutively added to performance variables, which results in new values for gross returns minus feed costs per sow per year. The economic importance of a deviation equals the difference between the original and the corresponding new value of gross returns minus feed costs per sow per year.

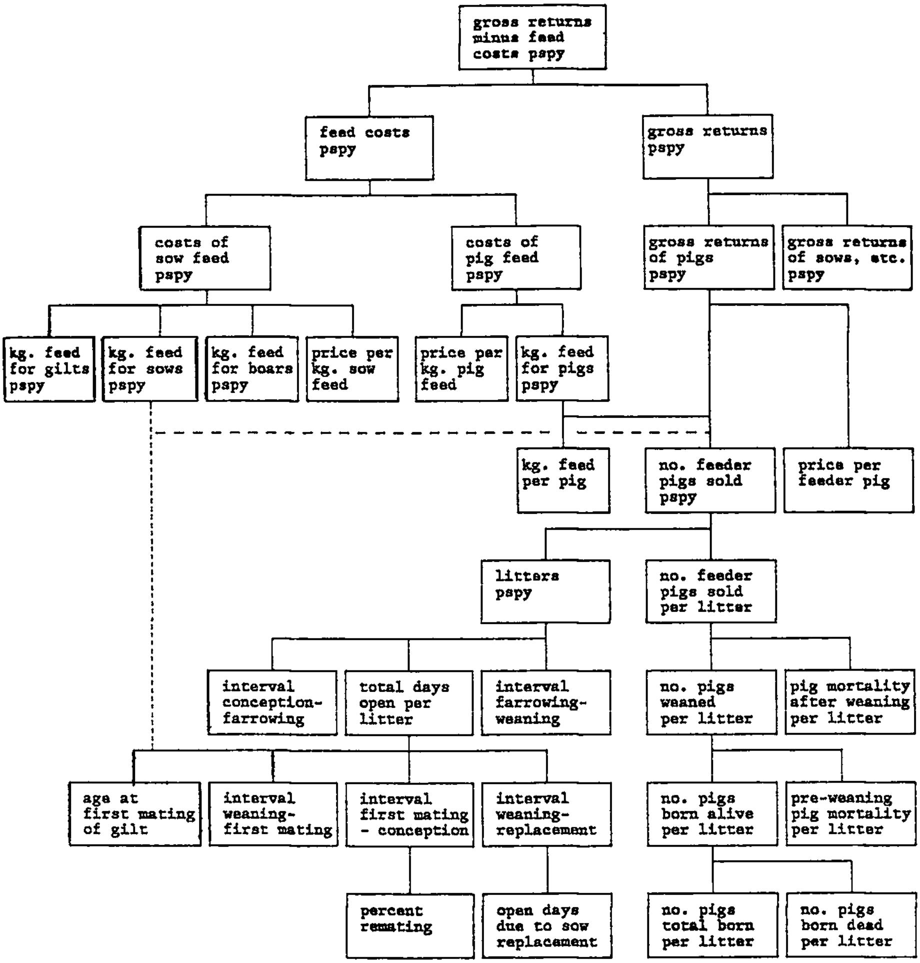

Figure 2. The analysis scheme used in the conceptual model (——: arithmetical relations, ----: feeding relations, pspy = per sow per year)

2.3.2. *Statistical importance*

As a measure of statistical importance, the traced deviation of a variable j (TD_j) is related to its standard deviation (SD_j). The statistical importance of a deviation increases as the ratio between traced deviation and standard deviation increases, and has been derived from the well-known t-statistics (Ostle, 1963; Warpole, 1982). In algebraic terms:

$$SI_j = TD_j / SD_j \quad (6)$$

where:

SI_j = statistical importance of a deviation in performance variable j;
TD_j = traced deviation of a performance variable j;
SD_j = standard deviation of a performance variable j.

Standard deviations must be obtained for each of the three types of analysis. Standard deviations for trend analysis are calculated as the square root of estimated residual variance ($\hat{s}_j$) of the linear trend model used for obtaining the predictions. The estimated variance is calculated as follows:

$$\hat{s}_j^2 = \sum_{t=1}^{T-1}(y_{tj} - \hat{y}_{tj})^2 / (n\text{-}2) = \sum_{t=1}^{T-1}\hat{e}_{tj}^2 / (n\text{-}2) \qquad (7)$$

where:

$\hat{s}_j^2$ = estimated variance for performance variable j;
n-2 = degrees of freedom (n = T-1 = number of observations);
The remaining symbols have been previously defined.

For comparative analysis, standard deviations of the group of similar farms are regularly made available in the Netherlands by the National Extension Service (Baltussen *et al.*, 1988). For comparative trend analysis, the standard deviations (of the slopes $\hat{n}_j$ in equation (5)) required to determine statistical importance of deviations are also obtained from external sources.

2.3.3. Relevance of a deviation

In determining the relevance of a deviation, both the economic and statistical importance of a deviation are taken into account. The relevance of a deviation is calculated by multiplying the economic importance with the absolute value of the statistical importance of a deviation in performance variable j. In formula:

$$RD_j = EI_j * |SI_j| \qquad (8)$$

where:

RD_j = relevance of a deviation in performance variable j;
EI_j = calculated economic importance of a deviation in performance variable j (in Dfl.);
SI_j = calculated statistical importance of a deviation in performance variable j.

The absolute value in the formula is used only to avoid changes in sign in the economic importance of a deviation. Thus, economic importance and relevance of a deviation always have the same sign.

As an illustration, an example is given in Table 1. With respect to the first variable (j = 1), actual value (AV_1) of litters per sow per year is 2.01, and standard value (SV_1) is 2.15. So, the traced deviation (TD_1) equals -0.14. With standard deviation (SD_1) being 0.10, the absolute value of the statistical importance is 1.40. The relevance of the deviation (RD_1) can then be determined (-138.74) by multiplying the absolute value of statistical importance (SI_1) by Dfl. -99.10, the calculated economic importance of the deviation (EI_1). Using this formula, all deviations are on the same scale and easily compared.

Table 1. Calculation of the relevance of deviations for some variables

Variable j*	AV_j	SV_j	TD_j	SD_j	$\lvert SI_j \rvert$	EI_j	RD_j
1. litters pspy	2.01	2.15	-0.14	0.10	1.40	-99.10	-138.74
2. pigs born alive pl	10.80	10.67	0.13	0.50	0.26	17.09	4.44
3. % pig mortality	18.00	15.21	2.79	4.40	0.63	-45.81	-28.86
4. fe pigs sold pl	8.86	9.05	-0.19	0.60	0.32	-29.42	-9.32
5. fe pigs sold pspy	17.80	19.45	-1.65	2.00	0.83	-149.49	-123.33
6. pig feed pp	25.00	29.04	-4.04	2.40	1.68	59.68	100.27
7. sow feed pspy	1070.15	1107.78	-37.63	64.70	0.58	18.81	10.94

* pspy = per sow per year, pl = per litter, fe = feeder, pp = per pig, remaining abbreviations: see text

2.4. Further analysis of deviations

The third stage of individual farm analysis is a further analysis of deviations. In determining deviations that must be subject to further analysis, all deviations are screened for relevance. As discussed before, deviations between performance and standards always exist. The question is at what level of deviation do they become relevant. For this purpose the conceptual model uses the so-called relevance diagram, outlined in Figure 3.

The relevance diagram helps to determine important levels of deviation. Relevant deviations may be intolerable if they have a negative economic importance (weaknesses) or be desirable if they have a positive economic importance (strengths). The diagram is based on the principle of double relevance. If the relevance of a deviation varies around zero (stage 0), it is presumed that the deviation is irrelevant, and no further analysis is needed.

If the deviation falls into stage 1, it may be relevant and a previous time-period is checked to assess the deviation is a radical alteration or the result of a slow change in performance. If the deviation falls into stage 2, the deviation is considered to be relevant, and subject to further analysis. The diagram is symmetrical around zero, treating positive relevance of deviations in the same way as negative relevance. The choice of the boundaries, which are user defined, determines the level of analysis. If narrow boundaries are chosen, a greater number of differences will be relevant, whereas if wide boundaries are chosen, the converse is true.

Performance deviations that are relevant are subjected to further analysis. In practice, analysis of deviations is not worthwhile unless the factors that caused them are identified (Anthony and Dearden, 1980). Therefore, further analysis of deviations requires the combination of deviations to find common causes. First, deviations should be divided into those that are under the control of an individual farm manager and those that are not. Because results of the analysis should be interpreted and used as a guide for management decisions, further analysis is performed only on those deviations that are under manager control. To find causes, deviations should be related to each other to see to what extent relevant deviations are associated. This is a very difficult process, for which years of special training and experience are normally required.

In finding causes it may be valuable to find out that some deviations are relevant and others are not. So, information both on relevance and irrelevance of deviations can be very important. However, further analysis is begun on the basis of relevant deviations. This is commonly called management by exception (Anthony, 1970; Castle *et al.*, 1987). The exceptions or relevant deviations between performance and standards are symptoms of strong and weak elements. These symptoms are then analyzed to pinpoint the cause of these elements. Management's attention is thus focused on the relatively small number of relevant deviations.

RD_j			
	stage 2	=	further analysis
	stage 1	=	check previous time period
	stage 0	=	no further analysis
0			
	stage 0	=	no further analysis
	stage 1	=	check previous time period
	stage 2	=	further analysis

Figure 3. The relevance diagram used in the conceptual model

2.5. Evaluating individual farm performance

During the last stage of individual farm analysis, deviations and causal factors are evaluated. To obtain a good indication of individual farm performance, causes of relevant deviations should be considered together with the original farm data, established standards, and calculated economic importance of deviations. If information provided by the information system is insufficient for sound valuation, it may be necessary to obtain information from additional sources. Strong and weak elements should be presented, ranked according to their impact on farm performance, and a report generated containing these strong and weak elements. For the sake of clarity and for the ease of reporting to the user, similar items should be grouped together. Examples of such grouping are nutrition, reproduction, and health care.

Once strengths and weaknesses have been identified, a farm manager may choose an appropriate course of action for dealing with these elements.

3. DESCRIPTION OF THE COMPUTER SYSTEM CHESS

3.1. General outline

For a long time, the major factor limiting the use of computers was the need to minimize the costs of hardware, data entry and storage. However, recent advances in information technology have changed this situation. The personal computer is now becoming an applicable tool for individual farmers because it is relatively easy to use, powerful, accessible and affordable, and because its price-performance ratio has declined (Huirne, 1990). These advances will increase the amount of farm specific data available, which can be used for making economic calculations for individual farms.

Most stages of individual farm analysis which were described earlier, are currently performed manually. This is a time-consuming and cumbersome process and, therefore, it is not performed frequently. Therefore, the personal computer system CHESS (Computerized Herd Evaluation System for Sows) has been designed, which uses the technique of individual farm analysis. CHESS consists of several modules, as shown in Figure 4.

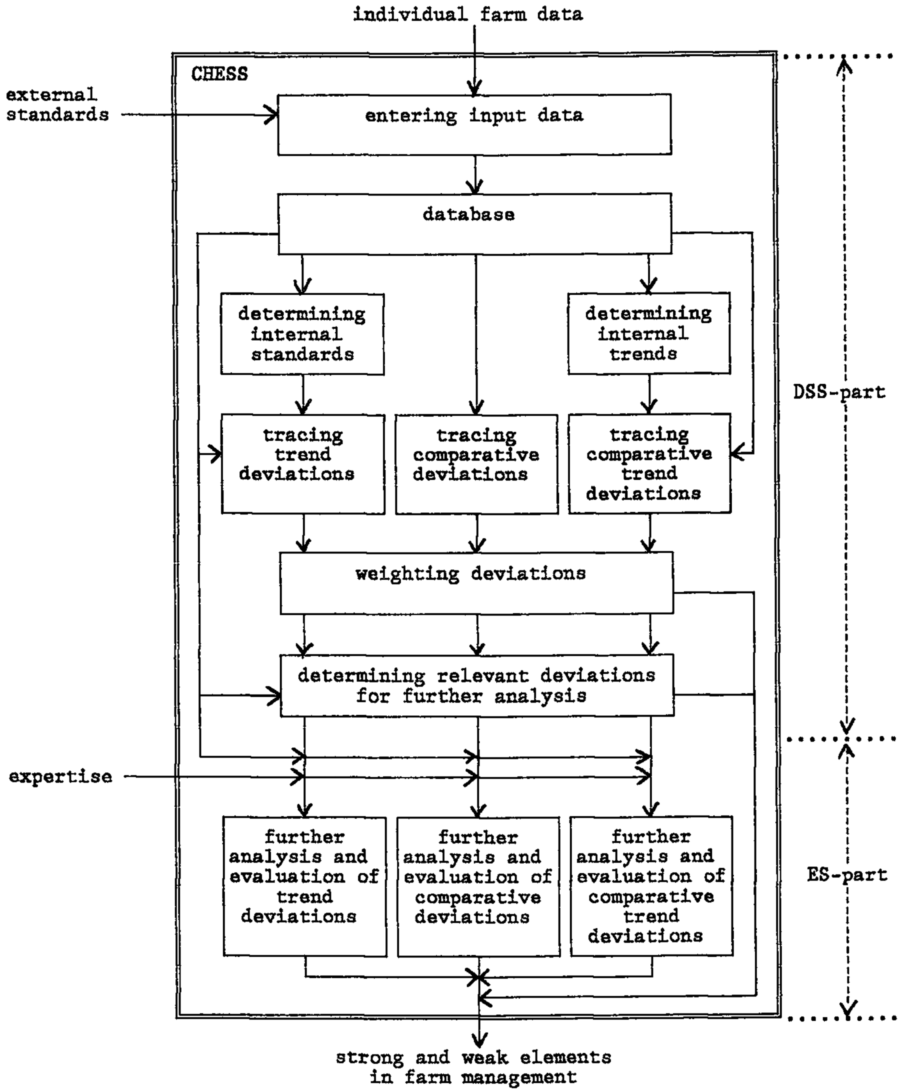

Figure 4. Architecture of CHESS

Within CHESS two groups of modules are being considered: decision support systems (DSS) and expert systems (ES). A DSS can be described as an interactive, computer-based information system that utilizes decision rules and models, coupled with a comprehensive database to support the decision making process (Turban, 1988). DSS allow the decision maker to retrieve data and test alternative solutions during the process of problem solving. DSS, therefore, are focussed on improving decision making effectiveness (Keen and Scott Morton, 1978). An ES is commonly defined as a computer program using expert knowledge to attain high levels of performance in a narrow problem area (Hayes-Roth *et al.*, 1983; Waterman, 1986). Thus, an ES combines knowledge of a particular domain with an inference capability, enabling the system to reach a level of decision making performance comparable to that of human experts in the given domain. In CHESS, the ES are integrated into the DSS by using the DSS results of a computerized quantitative analysis as input for the ES. Both the DSS-part and ES-part are described in more detail below.

3.2. The DSS-part

DSS are particularly suited for determining farm performance and standards, to calculate deviations and to rank these deviations according to their economic and statistical importance. To provide these performances nine modules are being considered within the DSS-part of CHESS, as indicated in Figure 4. The data entry module directs the user through the data entry procedure for the individual farm under consideration and the external standards. The module stores all input values in the database. Default data sets have been included in this module, and they can serve as a starting point for data entry. When only a few items in the default data set require changing, this can significantly reduce the time required for data entry. For new users, default data sets provide a working example of the system's input requirements (King and Dijkhuizen, 1988). Consistency checks are incorporated.

The process of tracing deviations is divided into three modules, one for each type of analysis. The first type concerns trend analysis, where actual farm performance is compared with internal standards. The internal standards are predictions of the farm performance variables based on historical data. Therefore, before comparison is made, the actual farm performance variables are read in the database and standards are calculated in the module "determining internal standards" (Figure 4). The second type of analysis concerns comparative analysis. The module "tracing comparative deviations" compares actual farm performance with the average performance of similar farms over the same time-period. Both the farm performance parameters and external standards are provided by the database. The third type of analysis concerns comparative trend analysis. To trace deviations, the historical development of farm performance (internal trends) is compared with the average development of performance of a group of similar farms (external trends) during the same time by the module "tracing comparative trend deviations".

After tracing deviations, the three types of deviations are weighted by the "weighting deviations" module, which involves calculating the economic and statistical importance of deviations between performance and standards. All deviations are converted to the same units and can therefore be compared, and ranked according to their economic impact. The final module of the DSS-part of CHESS determines which deviations are relevant to subject to further analysis.

To illustrate the protocol described above, the CHESS analysis of a sample farm is presented below. The main characteristics of the sample farm and standards used for comparative analysis are summarized in Table 2. Note that only a comparative analysis is carried out.

Table 2. Main herd characteristics of the sample farm and external standards used for comparative analysis

		External standards	
	sample farm	mean	SD*
Number of sows per farm	103.0	151.1	39.34
Litters per sow per year	2.17	2.23	0.18
Pigs born alive per litter	10.8	10.4	0.34
Percent pig mortality	19.5	10.8	6.97
Feeder pigs sold per litter	8.4	9.3	0.79
Feeder pigs sold per sow per year	18.3	20.9	2.62
Weight feeder pigs sold (kg)	29.0	25.9	1.79
Feed consumption per sow per year (kg)	1101.2	1102.2	89.23
Feed consumption per pig (kg)	47.0	32.8	7.25
Gross returns minus feed costs per sow per year (Dfl.**)	494.5	681.0	162.69

* SD = standard deviation
** Dfl. = Dutch guilders

As shown in Table 2, the herd size of the sample farm is below standard. The farm raised less pigs per sow per year as a result of less litters per sow per year and a higher pig mortality. Together with the high feed consumption per pig, these figures caused a low profit per sow per year. The major comparative analysis results of the DSS-part are presented in Table 3.

The DSS-part of CHESS found one strong element in farm management: "price of sow feed". This variable has a positive economic importance (EI_j) of Dfl. 51.3 (51.3 Dutch Guilders). Important weak elements are "feed consumption per pig" (EI_j = Dfl. -193.5) and "percent pig mortality" (EI_j = Dfl. -113.3). Deviations in these two base variables both have a considerable Statistical Importance (SI_j) of 1.96 and 1.45 respectively. Note that the DSS-part of CHESS does not take relations between deviations in performance variables into account. Therefore, the high "feed consumption per pig" is not corrected for the relatively high "weight feeder pigs sold", and both weak elements "feeder pigs sold per sow per year" and "feeder pigs sold per litter" are mentioned by the DSS.

Table 3. Major DSS-results of comparative analysis of the sample farm*

Variable j	Economic Importance (EI_j)**	Statistical Importance (SI_j)
STRONG ELEMENTS:		
Price of sow feed (100 kg)	51.3	1.04
WEAK ELEMENTS:		
Feed consumption per pig (kg)	-193.5	1.96
Gross returns minus feed costs per sow per year	-163.5	1.00
Pig feed per sow per year (kg)	-134.2	1.65
Feeder pigs sold per sow per year	-130.4	0.93
Percent pig mortality	-113.3	1.45
Pig feed cost per sow per year	-105.6	1.25
Feeder pigs sold per litter	-98.2	1.14
Interval farrowing-weaning	-30.1	2.45

* boundaries used in the relevance diagram (see Figure 3) are 50 and 100

** per sow per year (in Dfl.)

3.3. The ES-part

Grouping deviations to discover common causes and to draw final conclusions on - overall - herd performances require years of special training, education and experience. For these final parts of the individual farm analysis, therefore, ES are used in CHESS, one for each type of analysis (Figure 4). The ES are developed using the DELFI-2 empty expert system shell (Lucas and De Swaan Arons, 1987). The architecture of DELFI-2 is based on the widely accepted EMYCIN-system (Buchanan and Shortliffe, 1984). The components of the ES-modules are outlined in Figure 5. The proces of knowledge acquisition for these ES are described in the next section.

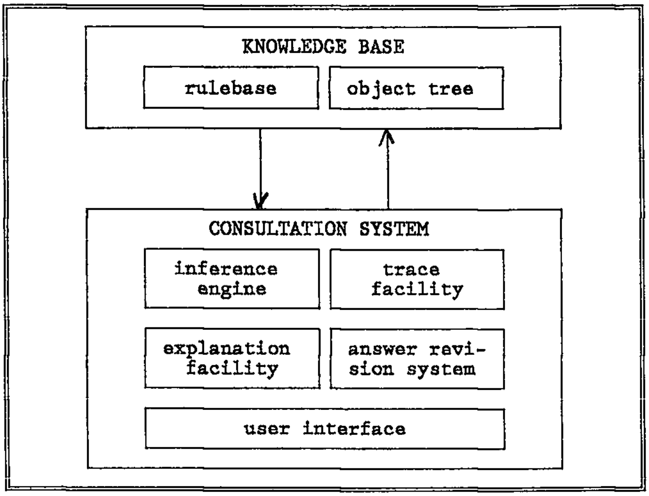

Figure 5. Components of an ES in the ES-part of CHESS

The first component presented in Figure 5 is the knowledge base containing the expert's domain-knowledge, and the second component is the consultation system consisting of elements that manipulate the knowledge base. Two parts can be distinguished in a knowledge base. The first part consists of a set of production rules, called the rulebase, which is basically used to encode the heuristic expert knowledge on individual farm analysis. The second part is a so-called object tree or scheme, which is used to supply declarative information during a consultation. Declarative information is provided during ES-consultation in order to acquire detailed information on variables used. The consultation system has the following five main elements: (1) an inference engine, which uses and controls knowledge available in the knowledge base, (2) an explanation facility, which allows the user to browse through the knowledge base to investigate production rules and established facts, (3) a trace facility, which gives the user relevant information about which part of knowledge is scanned at a certain time, (4) an answer revision system, which supplies an additional opportunity for revision of answers given by the user of the system during and after a consultation session, and (5) a user interface, which provides the communication between the ES-part of CHESS and the user. The inference engine uses backward chaining as its control strategy. Backward chaining can be described as an inference method where the system starts with what it wants to prove and tries to establish the facts it needs to prove (Waterman, 1986).

A production rule, derived from an expert's domain knowledge (see also the next section), has an IF-part and a THEN-part. The IF-part consists of one or more conditions and the THEN-part of one or more actions. The conditions are linked together with AND- and OR-operators. The actions to be performed if the conditions are fulfilled form the final part of the rule. Each conclusion is associated with a so-called certainty factor (CF), offering domain experts the opportunity to express their uncertainty due to incomplete or inexact knowledge. Each ES in CHESS includes between 250 and 300 rules, of which by means of illustration one is being presented:

RULE 10
IF 1.0 Percent remating of the herd is high
OR
1.1 Interval first mating-conception of the herd is long
2.0 Number of pigs total born of the herd is low
THEN 1.0 There is suggestive evidence (0.60) that the mating moment of sows in the herd is wrong

The output of an ES includes the results of its particular type of analysis. Six major areas for special attention are analyzed and evaluated: (1) nutrition, (2) health care, (3) reproduction, (4) housing, (5) input and output of animals, and (6) prices. Their choice has been made within the framework for an integrated information system for swine farms in the Netherlands, called an information model (Verheijden *et al.*, 1985). The overall impression of the sow herd is determined from the six major areas. As mentioned before, the input for the ES includes information from the database and the output of the DSS (Figure 4). For example, a relation between variables and conclusions in the reproduction area is outlined in Figure 6, which demonstrates production rule 10. Relations between mating moment, fertility observation, and reproduction are established in other rules. The output of the system is written in natural language, which can easily be read by the user. The comparative analysis results of the ES-part of CHESS concerning the sample farm are outlined in Table 4.

As shown in Table 4, the "overall impression of the herd" is bad with certainty 0.20. This is mainly a result of the "reproduction" and "input and output of animals"-areas. Special attention should be paid to "piglet mortality". Because the ES-part of CHESS takes relations between performance variables into account, the high "feed consumption per pig" is compensated by the high "weight feeder pigs sold" (see Tables 2 and 3), which results into a "normal" qualification for "feeding amount" in Table 4.

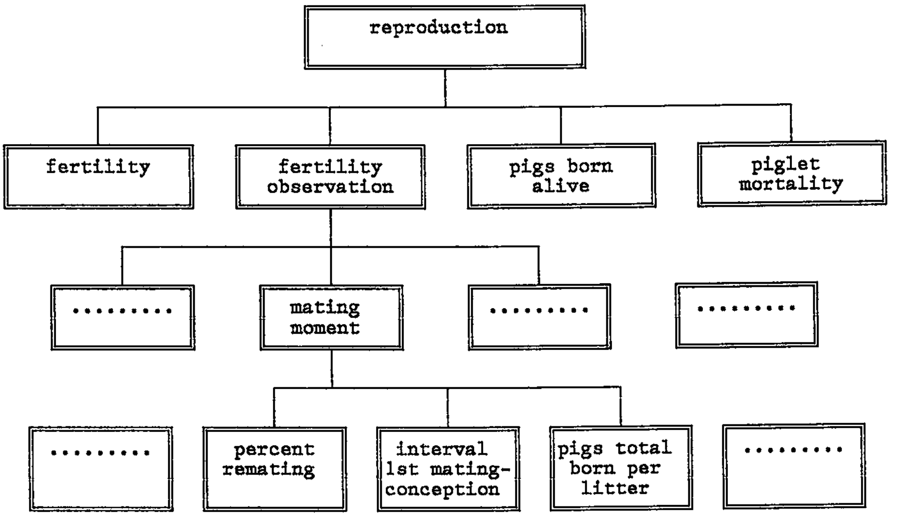

Figure 6. Structure of the reproduction area

Table 4. Major ES-results of comparative analysis of the sample farm

Area for special attention	outcome	certainty (CF)
OVERALL IMPRESSION OF THE HERD	BAD	0.20
- NUTRITION	NORMAL	0.60
. feeding amount	normal	0.50
. division of feed	normal	0.50
. feed costs	normal	0.60
- HEALTH CARE	NORMAL	0.80
. sow herd immunity	normal	0.60
. infection pressure	normal	0.60
. preventive actions	normal	0.50
- REPRODUCTION	BAD	0.21
. fertility	normal	0.70
. fertility observation	normal	0.70
. pigs born alive	normal	0.80
. piglet mortality	high	0.60
- HOUSING	NORMAL	0.80
. size of buildings	small	0.17
. quality of buildings	normal	0.60
- INPUT AND OUTPUT OF ANIMALS	BAD	0.45
- PRICES	GOOD	0.49

4. KNOWLEDGE ACQUISITION FOR THE ES OF CHESS

Knowledge acquisition is the transfer and transformation of problem-solving expertise from some knowledge source to the knowledge base of an ES (Buchanan *et al.*, 1983). Sources of knowledge used for filling the knowledge base of the ES in CHESS include human experts, textbooks, reports, databases, empirical data, and the developer's own experience. However, the main source was the human domain expert. Two questions arose: (1) which person should be considered an expert, and (2) how many experts to consult. The first question concerns the definition of an expert. According to Larkin *et al.* (1980) and Johnson (1983), an expert is a person who is able to do things others cannot, because of training and experience. Experts (1) are not only proficient but also smooth and efficient in the actions they take, (2) possess a wide knowledge base and have protocols and caveats for applying it to problems and tasks, (3) are good at abstracting information from large quantities of raw data, and (4) are good at recognizing problem patterns. The second question relates the number of experts to use for acquiring knowledge for the ES in CHESS. There are two major swine breeding regions in the Netherlands, one in the southern part and one in the eastern part of the country. With help from the National Swine Extension Service, one extension worker was selected from each of the two major regions on the basis of the four expert characteristics. They could be considered as experts in individual farm analysis, having gained their expertise over many years of training, education, and experience. Choosing more than one expert made it also possible to gain insight into the similarity between their expertise and experiences.

The two experts in the domain of individual farm analysis were interviewed independently. There are several methods for acquiring domain knowledge for an ES (Buchanan *et al.*, 1983; Waterman, 1986; Kidd, 1987), two of which were combined to obtain the knowledge base for the ES in CHESS, namely the observational method and the intuitive method. The observational method relies on watching the experts solving real farm analysis problems. Within this method "thinking aloud" protocols were used, which can be referred to as "protocol analysis" (Hayes, 1982; Waterman, 1986; Kuipers and Kassirer, 1987; D'Ydewalle and Delhaye, 1988). Using such protocols, the experts gave information on the structure and content of the expertise necessary for analyzing individual farm records. The protocol analysis was followed by a refinement phase in which the experts made comments on the transcript of the interview-session. The intuitive method relies on introspection by the domain experts. Using this method, the knowledge engineer responsible for knowledge acquisition, studied and interacted with both the experts and relevant literature in order to become familiar with the major problem solving methods in the field of individual farm analysis (Waterman, 1986). The knowledge engineer thus became a pseudo-expert. Using this knowledge, the knowledge engineer developed a representation of expertise, which was then checked against the opinion of the domain experts.

Having finished the knowledge acquisition sessions, the knowledge obtained could be built into the ES of CHESS because it was concrete enough to be translated into production rules for the knowledge bases. Furthermore, the expertise of both experts proved to be consistent and complementary rather than conflicting and, therefore, the production rules were derived from the expertise of both domain experts.

5. VALIDATION OF THE COMPUTER SYSTEM CHESS

5.1. General concepts

Validation is an important stage in developing computerized systems, which may be described as comparing the computer system with the observed world (Gilchrist, 1984). Measurement of the validity of any system, however, is a difficult issue. This is especially the case when ES are considered which use symbolic problem solving techniques and heuristics to produce conclusions. This may partially explain why no validation methods for ES could be found in the literature.

Naylor and Finger (1967) developed a three-stage validation concept: (1) a rationalist stage of ensuring that assumptions are in accordance with the theory, experience and relevant general knowledge, (2) an empirical stage in which the model's assumptions are subjected to empirical testing where possible, and (3) a positive stage of comparing input-output transformations generated by the system to those in the real world. The first two stages are referred to as "internal" validation, and the last stage as "external" validation (Taylor, 1983; Huirne *et al.*, 1990). Internal validation can thus be described as ensuring that the right answer, decision or recommendation is provided by the correct method, and that each equation or part of the system has a logical basis, uses correct parameters and is correctly written. A system can also be validated externally by comparing its performance against the performance of the real world, in which the system is considered as a "black box". Because systems are usually unable to reproduce or predict the entire real environment, external validity must conclude whether the use of the system is appropriate for the observed and expected errors. Information should be produced that enables the user of the system to conclude whether to accept or reject the system's solution or recommendation. This may include a sensitivity analysis in which the values of the parameters used in the system are systematically varied over some range of interest to determine whether and how the solution or recommendation changes (Anderson, 1974; Dent and Blackie, 1979; Gass, 1983).

In relation to validating ES, Gaschnig *et al.* (1983), and Gaultney (1985) note that besides the validity of the answers with respect to reality, the speed and efficiency with which the correct answers are provided are also important. In those situations where a comparison with reality is impossible, such as in analyzing individual farms, agreement with current expert opinion should be used.

5.2. Validation of CHESS

Validation of CHESS involved both internal and external validation. Internal validation started during the development process of the modules of CHESS. The logical structure, the variables and parameters used, and the normal behavior of the modules and the system as a whole were continuously checked. For this type of validation, a multi-disciplinary advisory group (including the domain experts, a veterinary expert, and experts in farm management, swine breeding, and mathematics) was used to review the modules and the system in detail. Subsequently CHESS was subjected to a two part external validation procedure: (1) a sensitivity analysis of the DSS-part and ES-part of CHESS separately, and (2) a field test of the system as a whole. The internal validation and the sensitivity analysis of the external validation, and the results obtained are described in detail elsewhere (Huirne *et al.*, 1990). The field test is outlined below.

The field test of CHESS was carried out to measure the performance of the entire system compared to the performance of the domain experts. Five swine farms were randomly selected from the geographical region in which the two domain experts, used for knowledge acquisition, worked. It is assumed that the experts are equally familiar with the five farms selected from their region. The field test was performed as follows. First, the experts made an individual farm analysis of their five "familiar" farms, using the farm data provided by their information system and other information available. The experts were asked to analyze each farm using their usual protocol and taking the same amount of time. Where possible, the domain experts were requested to rank the economically most important strong and weak elements of the farm's performance. The experts were then asked to make an analysis of the five farms of their colleague such that the five farms of the one expert are analyzed by the other, and *vice versa*. Because the experts are unfamiliar with these farms, they could only use the farm data provided by the information system for analysis, without any other specific information on the herd. After all ten farms were analyzed by the two domain experts, they were analyzed by CHESS. Finally, the results of the analysis of the "familiar" and "unfamiliar" farms were compared with each other and with the results of CHESS.

It is difficult to compare and present results of the ES-part of CHESS for particular farms since the ES output consists of text pages written in a natural language. However, each conclusion is connected with a so-called certainty factor (CF), which is a number between -1.00 and +1.00 that indicates CHESS' certainty or confidence in the validity of the conclusion. A conclusion with CF +1.00 means that CHESS is absolute affirmative about it, while a conclusion with CF -1.00 means that the system is absolute negative about it. If a CF equals 0 (zero) it is totally unknown to CHESS. The experts were asked to express their analysis results (conclusions) also with certainty factors (CF). The conclusions and the corresponding CF are used for comparing the results of the experts and CHESS. CF-values in each area under consideration were divided into three classes: CF-values which equaled 0 (zero) were placed in class A, CF-values between -0.01 and -0.34 or between 0.01 and 0.34 in class B, and CF-values less than -0.35 or greater than 0.35 in class C. The percent test agreement (PTA) between CHESS and experts in each area, defined as percent CF-values classified into the same classes ((A,A), (B,B) and (C,C)). Some major results are presented in Table 5, in which the CF-classes per area and per type of analysis have been summarized.

From Table 5 it can be calculated that the percent test agreement between CHESS and experts on familiar farms was 59% ((199+36+14) / 420) which can be broken down into test agreements of 60% for trend analysis, 62% for comparative analysis, and 56% for comparative trend analysis. The percent test agreement between CHESS and the expert on unfamiliar farms was slightly higher: 61% in general, consisting of a test agreement of 61% for trend analysis, 65%, for comparative analysis, and 59% for comparative trend analysis.

In the field CHESS should be used as a system for early detecting of problems or opportunities and it is, therefore, important that early stages of such changes are not overlooked. Table 5 provides a basis for calculating the occurrence of such errors. CHESS may be considered to have overlooked strengths or weakness if the CF given by CHESS fell into class A while the corresponding CF given by the experts fell into the classes B or C. The percent mis-classification errors turned out to be 4% ((17+1)/420; see Table 5.A) between CHESS and experts on their familiar farms and 4% ((18+0)/420) between CHESS and experts on unfamiliar farms. Both these mis-classification errors were mainly found in the reproduction area and in the comparative farm analysis.

Looking to the summations (n) of the classes in Table 5, there were considerable differences between CHESS and the experts. CHESS classified 52% of the CF-values into class A, 28% in class B and 20% in class C, with small differences between the three types of analysis. The experts, however, classified about 74%, 21%, and 5% in the classes A, B, and C respectively, with considerable differences between the types of analysis. Only the results of the comparative analysis were comparable with CHESS. This also indicates that the experts mainly concentrated on comparative analysis.

Table 5. Results of CHESS versus experts on familiar and unfamiliar farms

A. Familiar farms

		Expert			
	class*	A	B	C	n
CHESS	A	199**	17	1	217
	B	75	36	8	119
	C	44	26	14	84
	n	318	79	23	420

B. Unfamiliar farms

		Expert			
	class*	A	B	C	n
CHESS	A	199**	18	0	217
	B	64	48	7	119
	C	39	34	11	84
	n	302	100	18	420

* class A: no positive (strengths) or negative (weaknesses) conclusions
class B: positive/negative conclusions with low certainty (CF ≤ |0.34|)
class C: positive/negative conclusions with high certainty (CF ≥ |0.35|)
** numbers refer to the total number of conclusions involved

5.3. Comparison of the experts

So far, it has been assumed that the two domain experts used in validation of CHESS had the same level of expertise. The individual farm analysis results of the experts can be compared with each other in two ways. Firstly, the results of the analysis on their familiar farms can be compared with the results of the analysis on the unfamiliar farms. This would indicate the value of familiarity with the farms being analyzed. The second possibility is to compare the results of one expert with the results of the other, which gains insight into differences between the experts. The results of these two comparisons are given in Table 6.

Table 6. Results of the comparison of the experts

A. Expert on familiar farms versus unfamiliar farms

	class*	A	B	C	n
		Expert unfamiliar farms			
Expert familiar farms	A	275**	38	6	319
	B	24	47	6	77
	C	1	14	19	24
	n	300	99	21	420

B. Expert I versus expert II

	class*	A	B	C	n
		Expert II			
Expert I	A	275**	39	6	320
	B	23	47	12	82
	C	1	8	9	18
	n	299	94	27	420

* class A: no positive (strengths) or negative (weaknesses) conclusions
class B: positive/negative conclusions with low certainty (CF ≤ |0.34|)
class C: positive/negative conclusions with high certainty (CF ≥ |0.35|)
** numbers refer to the total number of conclusions involved

The percent test agreement in farm analysis results between the expert on familiar and unfamiliar farms, and between the two experts was 79% ((275+47+9)/420; see Tables 6.A and 6.B). The experts on familiar farms and on unfamiliar farms totally disagreed in 2% of the cases ((1+6)/420; see classes (C,A) and (A,C) in Table 6.A)). This disagreement cannot be traced back to any particular area. Experts on their familiar farms tended to mention fewer elements (Table 6.A).

The total disagreement between the two experts was 2% only, which also cannot be traced back to a certain area. Small differences between the experts included that expert I tended to slightly over-estimate strengths and weaknesses, compared to expert II. It can be concluded that only minor differences occurred between the two experts, and therefore, the assumption that the two experts used the same level of expertise cannot be rejected.

6. DISCUSSION AND OUTLOOK

Current systems for providing information to farmers do not go far beyond the traditional record-keeping approach. They are essentially accounting systems for technical and economic farm data, registering data on production levels, quantities and prices of inputs and products, and on costs and returns. Extending these traditional systems with - computerized - decision support and expert systems can make them more valuable and appropriate for the decision-making process of individual farmers, as shown in this chapter with respect to individual farm analysis.

A key-issue in individual farm analysis is that a small deviation between farm performance and a standard can be the start of a significant and permanent deviation over future periods, while in other cases a small deviation may be a coincidence and of short-term duration. It is desirable to detect the first situation at an early stage so that further analysis and corrective actions can be taken rapidly. In the second situation no further analysis is required, and inappropriate responses should be avoided. Taking into account both the economic and statistical importance of a deviation in a diagram of relevance has shown to be a valuable approach to cope with this issue. Modifying the boundaries in this diagram can help to get a further insight into the impact of the various deviations.

The construction of the conceptual model presented in this chapter includes three types of analysis: trend analysis, comparative analysis, comparative trend analysis. This provides for the detection of the most important strengths and weaknesses in the management of a farm. However, conflicting results may be obtained between each type of analysis. For instance, reproduction may be indicated a strong point in trend analysis, but a problem in comparative analysis. It is difficult to cope with this problem. Therefore, the conceptual model presents the results of each type of analysis separately, giving farm managers the opportunity to choose the type they consider the most appropriate.

Standards for trend analysis are calculated with a linear trend model. More sophisticated models including stochastic models, seasonal models and exponential growth models, are not used because a linear trend model, while simple, is probably robust enough for the purposes described in this chapter. Although additional terms in a more sophisticated model might describe the past more accurately than the linear trend model, there is doubt about the stability of forecasts. In practice, the linear trend is often the only stable aspect that can reasonably be expected to continue into the short-term future (Gilchrist, 1976, 1984). One other simple relation used in the conceptual model is the linear relation between the economic importance (EI_j) and the statistical importance of a deviation (SI_j) for calculating the relevance of a deviation. As shown in the field test of CHESS, this linear relation turned out to work well. Additional research is desired, however, to provide a more theoretical basis for these types of relations.

The use of comparative analysis invites criticism of the limited value of between-farm comparison. When calculating standards for comparative analysis, farms must be organized into groups according to certain criteria. The farms within one group, however, may then differ considerably with regard to factors irrelevant to these criteria. Farms within the group may therefore be atypical. True representative standards can only be established by basing them on a large number of randomly selected farms; however it is unpracticable to conduct such a procedure. In general, a choice must be made between a large number of well-defined groups with only a small number of farms in each, or a reasonably large number of farms within each group but only a few, rather poor-defined groups. Since early detection of problems is an objective of individual farm analysis, it is very important that all data needed for the analysis be available at the time needed. In practice external data tend to be available too late.

To apply the conceptual model underlying the individual farm analysis in a computerized system, decision support (DSS) and expert system (ES) features have been combined and integrated. In the DSS-part, the problems of interest are fairly well structured, and DSS techniques are used to solve them. On the other hand, in the ES-part, the problems of interest are relatively poorly structured and expert practitioners provide a powerful source of successful procedures for problem solving. These procedures have the additional advantage that they are fitted to the information handling capabilities of human problem solvers (Johnson, 1983).

Several difficulties were met during the knowledge acquisition for the ES in CHESS. With the observational method, the experts solve individual farm analysis problems while describing aloud what is being done. Although the act of thinking aloud may slightly alter the expert's technique, the greater problem arises from the huge gaps which often occur in the description of the process. If the experts are asked to be more explicit, either during the session or after the session in an interview using the transcript of the session, they may construct a line of plausible reasoning to explain their behavior, rather than describe the actual problem-solving techniques used. Using two domain experts independently, the knowledge engineer was able to compare their behavior, and it could be concluded that their behavior was complementary rather than conflicting. A second problem relates to using an empty shell in developing CHESS. Expertise of the two domain experts is translated into production rules, which are stored in the knowledge base of the ES. One of the difficulties is the representation mismatch. This is the difference between the way the human experts normally state knowledge and the way it must be presented in the system (Buchanan *et al.*, 1983). Because the ES in CHESS are developed within the empty shell DELFI-2, neither the syntactic form of the production rules nor the method of handling uncertainty can be altered. Each production rule in the knowledge base must be connected with a so-called certainty factor, expressing the measure of belief or confidence about the production rule as a whole. It is difficult to find a balanced set of certainty factors for all rules.

Due to the nature of the ES in CHESS, it is hard to define a "gold standard" against which the system's performance can be compared. In validating CHESS a method has been developed for testing the system as a whole. Comparison with reality is not possible and, therefore, the system has been validated by comparing the system's answers with answers of the two domain experts. Two problems may arise with this method of validation. First, it may be hard to obtain a match between the conclusions of the system and the expert. Different experts may disagree on certain details or both the system and the expert may be wrong. Second, a domain expert is not always right, even in his area of expertise, which may result in a false sense of correctness with this method of validation (Gaultney, 1985). Other possible causes of differences between system and expert conclusions may include: (1) a certain part of the system is not completely right, and (2) the experts used additional knowledge, which is not yet incorporated into the system. So, it is difficult to determine under what situations or conditions differences between system and expert answers should result in modifying the system.

Using CHESS for analyzing the performance of individual sow herds, the major strong and weak elements in management are traced, and their economic impact is calculated. Where serious problems (weak elements) are found by CHESS, a more detailed analysis in depth of such problems could be necessary. Therefore, other systems must be developed for detailed analysis of these smaller areas, using more - and more detailed - farm data on such area. Potential areas are nutrition (for analysis of feeding-scheme for example), health care (for analysis of vaccination-program) and reproduction (for analysis of the replacement policy). If these systems become available and can be integrated into CHESS, a powerful and useful system will be obtained for analysis of the whole herd, and, if necessary, a detailed analysis in depth of certain (strong or weak) elements within the herd. At the moment (autumn 1990) CHESS is mainly used as a tool for teaching and research. It is also the intention to introduce CHESS into the extension work of the National Swine Extension Service and of some commercial advisory firms.

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CHAPTER 3

Validation of an integrated decision support and expert system for analysis of individual sow-herd performance

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ABSTRACT

Validation is an important and difficult stage in developing computerized systems. This is especially the case when expert systems are considered where symbolic problem solving-techniques and heuristics are used to draw conclusions. A methodology for validating the computer system CHESS, which determines strengths and weaknesses in the management of an individual swine breeding enterprise, has been developed. Both the decision support system and the expert system components of CHESS have been validated, and a field test of CHESS as a whole has been carried out. The field test resulted in a test agreement between CHESS and experts of about 60%. The percent mis-classification error turned out to be 4%. So, the knowledge of the experts has successfully been incorporated into the computerized expert system.

1. INTRODUCTION

The management of the modern swine breeding herd is becoming more difficult and important to the economic viability of the unit (Huirne, 1990). To support farmers in managing their herds, the computer system CHESS (Computerized Herd Evaluation System for Sows) has been developed. CHESS is a personal-computer system, which analyses individual farm records within an economic framework (Huirne *et al.*, 1990). To determine the strengths and weaknesses in the management of the pig enterprise, CHESS incorporates the following three types of analysis: (1) trend analysis, comparing actual herd performance against predictions based on a herd's historical data, (2) comparative analysis, comparing actual herd performance with average performance of similar herds, and (3) comparative trend analysis, comparing the historical development of herd performance against the average development of performance of similar herds.

CHESS consists of both a decision support system (DSS) and three expert systems (ES), used in a modular manner in which the output of the DSS is used as input to the ES (Figure 1). The DSS identifies and assesses the importance of relevant deviations between the performance and standards (tracing deviations, weighting deviations, and determining deviations for further analysis). The ES attempt to find the strengths and weaknesses in the management of the herd by combining and evaluating the previously identified deviations (further analysis of deviations, and evaluating individual farm performance). Thus, the ES in CHESS operate as additional components of the DSS. The input data needed for CHESS consists of individual farm data and external standards for the DSS, which are stored in the database, and expertise from human experts for the ES. For a detailed description of the computer system CHESS and its architecture reference is made to Huirne *et al.* (1990).

Validation is an important stage in developing computerized systems, which may be described as comparing the computer system with the observed world (Gilchrist, 1984). Measurement of the validity of any system, however, is a difficult issue. Especially ES are difficult to validate as they use symbolic problem-solving techniques and heuristics to produce conclusions. This may partially explain why no validation methods for ES could be found in the literature.

In this chapter, general validation concepts and the validation procedure used for CHESS are presented and discussed. Attention is focused on developing a methodology for validating both the DSS and ES components of CHESS, and the process of developing and carrying out a field test of CHESS as a whole is outlined. Finally, the results obtained and the potential use of the system both in the field and for further research work are described.

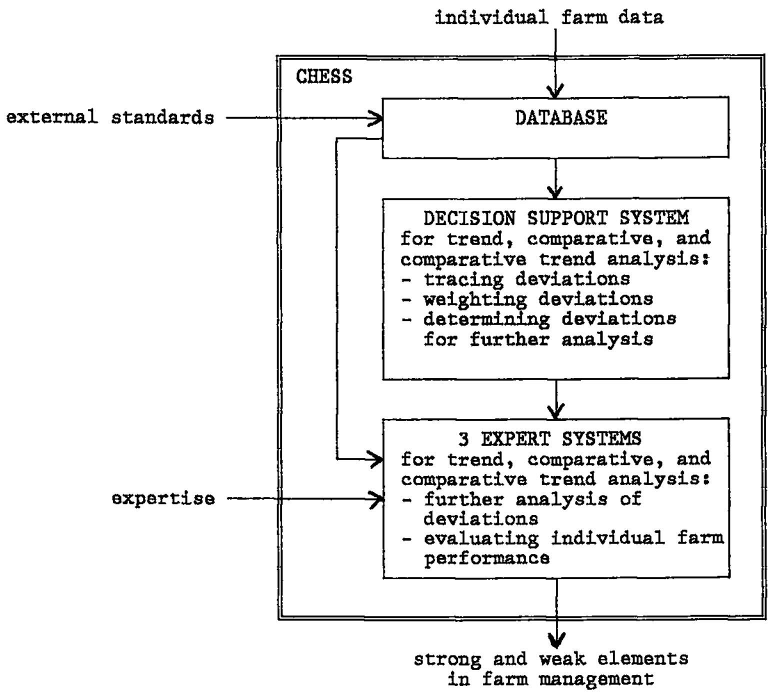

Figure 1. General architecture of CHESS

2. MATERIALS AND METHODS

2.1. Concepts of validation

In validating any system, attention should be focused on that part of the real world which is represented (McCarl, 1984). It is not necessary to reflect the real world perfectly, but it is essential to abstract reality such that it is adequate for the system's anticipated use.

Naylor and Finger (1967) developed a three-stage validation concept: (1) a rationalist stage of ensuring that assumptions are in accordance with the theory, experience and relevant general knowledge, (2) an empirical stage in which the model's assumptions are subjected to empirical testing where possible, and (3) a positive stage of comparing input-output transformations generated by the system to those in the real world. The first two stages are referred to as "internal validation", and the last stage as "external validation" (Taylor, 1983). Internal validation can thus be described as ensuring that the right answer, decision or recommendation is provided by the correct method, and that each equation or part of the system has a logical basis, uses correct parameters and is correctly written (Taylor, 1983; McCarl, 1984).

A system can also be validated externally by comparing its performance against the performance of the real world, in which the system is considered as a "black box" (Taylor, 1983). Because systems are usually unable to reproduce or predict the entire real environment, external validity must conclude whether the use of the system is appropriate for the observed and expected errors. Information should be produced that enables the user of the system to conclude whether to accept or reject the system's solution or recommendation. This may include a sensitivity analysis in which the values of the parameters used in the system are systematically varied over some range of interest to determine whether and how the solution or recommendation changes (Anderson, 1974; Dent and Blackie, 1979). External validation corresponds with the third stage of the validation concept of Naylor and Finger (1967).

Gass (1983) considers that a validation framework should also include "dynamic validity". Dynamic validation is concerned with determining how the system will be maintained during its life cycle so it will continue to be an acceptable representation of reality.

In relation to validating ES, Gaschnig *et al.* (1983) and Gaultney (1985) note that besides the validity of the answers with respect to reality, the speed and efficiency with which the correct answers are provided are also important. In those situations where a comparison with reality is impossible, such as in analyzing individual farms, agreement with current expert opinion should be used.

Two fundamental issues relate to validation of any model or system. First, the fact that a system behaves like reality for one set of inputs and operating rules does not guarantee that it will perform satisfactorily for a different set of conditions (Wright and Dent, 1969; Dannenbring and Starr, 1981). The outcome of a validation process is either a system which have been proved invalid, or a system for which the degree of confidence has been increased. In the latter case, the validation process provides information on strengths and weaknesses of the system. The importance of omitted model components can be considered and their relative importance assessed. However, the term "valid system" is often used to denote a system which did not fail when submitted to validation tests (Gass, 1983; McCarl, 1984). These problems lead to the second issue concerning the subjectivity of all validation procedures, which has been emphasized by Wright and Dent (1969) and Anderson (1974). There is no totally objective and accepted approach to validation, because validation necessarily includes (McCarl, 1984): (1) the uses of the system to validate, (2) the tests with which to validate the system, (3) the data to serve as a basis for comparison, and (4) the criteria to measure the (in)validity of the system.

2.2. Validation of CHESS

Validation of CHESS involved both internal and external validation. Internal validation started during the development process of the modules of CHESS. The logical structure, the variables and parameters used, and the normal behavior of the modules and the system as a whole were continuously checked. For this type of validation, a multi-disciplinary advisory group (including the domain experts, a veterinary expert, and experts in farm management, swine breeding, and mathematics) was used to review the modules and the system in detail. Modules belonging to the DSS-part of CHESS, principally a set of algorithms, were relatively easy to test. In developing the ES, individual production rules and the structure of the knowledge base were tested. Testing the whole ES was difficult because: (1) as mentioned above, ES use symbolic problem-solving techniques and heuristics, (2) it is almost impossible to check the 250 to 300 production rules, which form each knowledge base, as they are seldom independent of each other.

The result of this type of validation is not a valid/invalid assessment, rather an indication of areas of concern regarding CHESS's internal validity. Therefore, quantitative results were not obtained.

Subsequently CHESS was subjected to a two-part external validation procedure: (1) a sensitivity analysis of the DSS-part and ES-part of CHESS separately, and (2) a field test of the system as a whole. Sensitivity analysis consisted of successive "runs" of the DSS-part and ES-part in which the values of the parameters were changed successively, usually varying one parameter at a time. The resultant modification in DSS- and ES-output was analyzed to determine whether or not the changed parameter values are of material consequence, including the magnitude of any such changes.

The field test of CHESS was carried out to measure the performance of the entire system compared to the performance of the domain experts. Five swine breeding farms were randomly selected from the geographical region (eastern and southern region in the Netherlands) in which the two domain experts, used for knowledge acquisition (Huirne *et al.*, 1990), worked. It was assumed that the experts were equally familiar with the five farms selected from their region. The field test was performed as follows. First, the experts made an individual farm analysis of their "familiar" five farms, using the farm data provided by their information system and other information available. To facilitate comparison, six areas of special attention were considered in each case: (1) nutrition, (2) health care, (3) reproduction, (4) housing, (5) input and output of animals, (6) prices. These six areas correspond with the areas for analysis and evaluation in the ES-part of CHESS (Huirne *et al.*, 1990). The experts were asked to analyze each farm using their usual protocol and taking the same amount of time. Where possible, the domain experts were requested to rank the economically most important strong and weak elements of the farm's performance. The experts were then asked to make an analysis of the five farms of their colleague such that the five farms of the one expert were analyzed by the other, and *vice versa*. Because the experts were unfamiliar with these farms, they could only use the farm data provided by the information system for analysis, without any other specific information on the farm. After all ten farms were analyzed by the two domain experts, they were analyzed by CHESS. Finally, the results of the analysis of the "familiar" and "unfamiliar" farms were compared with each other and with the results of CHESS.

It is difficult to compare and present results of the ES-part of CHESS for particular farms since the ES output consists of text pages written in a natural language (Huirne *et al.*, 1990). However, each conclusion is connected with a so-called certainty factor (CF), which is a numerical value between -1.00 and +1.00 that indicates CHESS' certainty or confidence in the validity of the conclusion. A conclusion with CF +1.00 means that CHESS is absolute affirmative about it, while a conclusion with CF -1.00 means that the system is absolute negative about it. If a CF equals 0 (zero) it is totally unknown to CHESS. The experts were asked to express their analysis results (conclusions) also with certainty factors (CF). The conclusions and the corresponding CF are used for comparing the results of the experts and CHESS.

2.3. Materials used for validation

To gain more insight into the level of management on the farms under consideration, the principal descriptive parameters are presented in Table 1, and compared with typical commercial swine breeding herds in each region and in the Netherlands.

Table 1. Main herd characteristics of the five farms in each region involved in the validation, compared with regional averages and typical commercial swine breeding farms in the Netherlands in 1987

	Eastern region		Southern region		Average typical farms*
	5 farms	average*	5 farms	average*	
Number of sows per farm	142	123	162	132	130
Litters per sow per year	2.21	2.16	2.18	2.17	2.18
Pigs born alive per litter	10.3	10.6	10.4	10.3	10.5
Percent pig mortality	10.1	14.0	16.3	15.0	14.0
Feeder pigs sold per litter	9.2	9.1	8.8	8.8	9.0
Feeder pigs sold/sow/year	20.5	19.7	19.2	19.2	19.6
Weight feeder pigs sold (kg)	25	25	26	26	26
Feed consumption/sow/year (kg)	1111	1100	1138	1095	1100
Feed consumption per pig (kg)	33	32	35	33	32
Gross returns minus feed costs/sow/year (Dfl.)	683	672	688	746	708

* Baltussen *et al.* (1988)

As shown in Table 1, the herd size of the ten farms assessed is above average. In the eastern region on average the five farms raised more pigs per sow per year as a result of more litters per sow per year and a lower pig mortality. In the southern region the five farms had average biological performance, but the economic results were slightly lower. As the overall differences between the characteristics of the ten farms, the region averages, and the typical Dutch swine breeding farms in 1987 were relatively small, these farms were used *en bloc* for validation purposes.

Because individual farm analysis is to be used for early detection of problems, it is important to use accurate standards for comparison. For trend analysis, standards are calculated by CHESS and accuracy is not a problem. For comparative and comparative trend analysis, however, standards must be obtained from other - external - sources, and in general, these standards are not accurate because they include a time lag. In validating CHESS, the performance of the farms in the third quarter of 1988 were assessed. The main characteristics of the standards used are summarized in Table 2.

Table 2. Main characteristics of the standards used for comparative and comparative trend analysis

	Third quarter 1988		Trend/quarter**	
	mean	SD*	mean	SD*
Number of sows per farm	151.1	39.34	-0.432	1.286
Litters per sow per year	2.23	0.18	0.006	0.020
Pigs born alive per litter	10.4	0.34	0.041	0.072
Percent pig mortality	10.8	6.97	-0.453	0.810
Feeder pigs sold per litter	9.3	0.79	0.079	0.122
Feeder pigs sold/sow/year	20.9	2.62	0.226	0.329
Weight feeder pigs sold (kg)	25.9	1.79	0.007	0.156
Feed consumption/sow/year (kg)	1102	89.23	-9.761	21.431
Feed consumption per pig (kg)	32.8	7.25	-0.375	0.464
Gross returns minus feed costs/sow/year (Dfl.)	681	162.69	-4.943	31.353

* SD = standard deviation

** based on the 4 quarters of 1987 and the first 3 quarters of 1988

2.4. Outline of results

As described above, quantitative results from the internal validation are not obtained. Therefore, the results presented in this chapter concern the external validation of CHESS. The three types of analysis, i.e. (1) trend analysis, (2) comparative analysis, and (3) comparative trend analysis, performed by CHESS share many modules (Huirne *et al.*, 1990). Therefore, although all parts of CHESS are validated, to describe the validation results of all three types of analysis would involve considerable repetition.

Consequently, the sensitivity analysis results of only the comparative analysis are in this chapter. To gain insight into the validity of CHESS as a whole, results for the field test of all three types of analysis are described.

3. RESULTS

3.1. Sensitivity analysis

The effects of changes in the major production and price parameters were analyzed to investigate the behavior of the two main parts of CHESS. Alternative production and price levels used in the sensitivity analysis of the DSS-part of CHESS are summarized in Table 3. These variables were varied (-15% and +15% relative to the basic level) individually. The "gross returns minus feed costs per sow per year" was sensitive to changes in litters per sow per year, litter size, and feeder pig price (Table 3). Additional calculations showed that the value of an increased day of farrowing interval was Dfl. 3.24 (3.24 Dutch Guilders), and Dfl. 50 per extra pig born alive. In contrast, gross returns minus feed costs was little influenced by pig mortality and feed prices.

Table 3. Influences on "gross returns minus feed costs per sow per year" in the sensitivity analysis of the DSS-part of CHESS

	Gross returns minus feed costs*				
	Low 85%		Basic** 100%	High 115%	
Variable	abs	change		abs	change
Litters per sow per year	578	-22%	2.18	910	+22%
Pigs born alive per litter	570	-23%	10.5	919	+24%
Percent pig mortality	773	+4%	14.0	717	-4%
Price feeder pigs sold (23 kg)	499	-33%	83.3	990	+33%
Price piglet feed (per 100 kg)	817	+10%	76.4	672	-10%
Price sow feed (per 100 kg)	821	+10%	46.3	668	-10%

* the influences are given in absolute values (abs in Dfl.) and in changes relative to the basic situation (change in %) per sow per year. The basic gross returns minus feed costs are Dfl. 745

** values in the basic situation are given in original dimensions (average typical farms (Baltussen *et al.*, 1988))

Table 4. Influences on the certainty factor (CF) of the conclusion concerning "overall impression of the herd" in the sensitivity analysis of the ES-part of CHESS

	Overall impression of the herd*		
Variable	Negative code -1**	Basic code 0**	Positive code +1**
1. Litters per sow per year	-0.14	normal	0.21
2. Pigs born alive per litter	-0.11	normal	0.10
3. Percent pig mortality	-0.07	normal	0.07
4. Feed consumption per sow per year	normal	normal	normal
5. Feed consumption per pig	-0.07	normal	-0.06
6. Price feeder pigs sold (23 kg)	-0.07	normal	0.07
7. Price piglet feed (per 100 kg)	-0.04	normal	0.05
8. Price sow feed (per 100 kg)	-0.07	normal	0.07
Pigs sold per sow per year (1+2+3)***	-0.31	normal	0.28
Feed consumption (4+5)***	-0.10	normal	-0.06
Prices (6+7+8)***	-0.12	normal	0.11

* there were three types of conclusions on "overall impression of the herd":
- negative conclusion (CF < 0) concerns weaknesses,
- positive conclusion (CF > 0) concerns strengths,
- "normal" if the overall impression was not influenced (CF = 0)

** the variables used in the sensitivity analysis could take three values:
-1: a relevant deviation with a negative economic importance ("Negative")
0: an irrelevant deviation ("Basic")
+1: a relevant deviation with a positive economic importance ("Positive")

*** entire set of variables altered

The sensitivity analysis of the ES-part of CHESS was carried out by varying one variable at a time as outlined in Table 4. The base input for the ES consisted of variables which had a relevant deviation with a negative economic importance (weaknesses, code -1), with a positive economic importance (strengths, code +1), or variables without a relevant deviation (code 0) (Huirne *et al.*, 1990). Influences on the CF of the conclusion concerning "overall impression of the herd" are given in Table 4. The following three types of conclusions were possible: (1) conclusions with a negative impression (CF < 0) concerning weaknesses, (2) conclusions with a positive impression (CF > 0) concerning strengths, and (3) the conclusion "normal" (CF = 0) if "overall impression of the herd" was not influenced. The overall impression was also more sensitive to litters per sow per year and litter size, and less sensitive to pig mortality and feed prices. Note that only one variable was varied at a time, while for simulating strengths and weaknesses in practice, a group of variables must be varied.

Therefore, the influences on the overall impression were rather low. This may explain why negative changes in the value for litters per sow per year had a small effect on the overall impression variable. The overall impression of the herd was negatively influenced by both a negative and by a positive change in feed consumption per pig. Low feed consumption per pig had a positive economic importance (low feed costs) with a positive influence on the overall impression, but was often related to veterinary problems with a larger negative influence on overall impression of the herd.

The second part of Table 4 gives an indication on how the overall impression of the herd is influenced if more than one variable was changed at a time. It can be seen that a combined variation of variables of the same type is not just a summation of influences of individual variables. The low influence on the overall impression of the negative level of litters per sow per year (-0.14) was enlarged if litter size and pig mortality had also a negative level, compared with positive levels of these three variables.

3.2. Field testing

3.2.1. CHESS versus experts

In the field test, the results of CHESS were compared with the individual farm analyses of the two domain experts on the ten farms. The results of CHESS are presented for the six major areas for special attention in terms of their CF in Table 5. To aid interpretation, the positive and negative components of CF are treated separately by dividing each area into a positive and a negative part. The negative part of the CF indicate weaknesses, and the positive part strengths. If there are no strong or weak elements in a certain area, CF equals 0 (zero).

The average results of trend analysis for the ten farms are presented in Table 5.A. These include results of CHESS and results of experts on their familiar and unfamiliar farms. Both weak ("Neg") and strong ("Pos") elements in each area of special attention are given. Table 5.B contains the results of the comparative analysis and Table 5.C the results of the comparative trend analysis. The average figures for the experts was higher in comparative analysis than in the other two types of analysis. This may indicate that the experts concentrated on comparative analysis. CHESS, however, produced similar results in each type of analysis.

To assess the quality of farm analysis results, the 20 CF values (ten farms and one CF for each "Neg" and "Pos" element) in each area were divided into three classes. Conclusions CF which equaled 0 (zero) were placed in class A, CF values between -0.01 and -0.34 or between 0.01 and 0.34 in class B, and CF values less than -0.35 or greater than 0.35 in class C. The percent test agreement (PTA) between CHESS and experts in each area, defined as percent CF values classified into the same classes ((A,A), (B,B) and (C,C)), is also given in Table 5. High test agreements are obtained in the areas "nutrition", "health care", "reproduction" and "housing". Relative low agreement is found between CHESS and experts in the areas "in/output animals" and "prices". The latter may be due to the fact that CHESS uses DSS modules for determining the economic importance of all the deviations in these areas whilst the experts used only reasoning for obtaining their results.

Table 5. Results of the validation of CHESS on the ten farms

A. Results* of trend analysis

Area	CHESS		Expert familiar farms			Expert unfamiliar farms		
	Neg	Pos	Neg	Pos	PTA	Neg	Pos	PTA
Overall impression	-0.20	0.22	-0.45	0.41	65	-0.21	0.18	35
Nutrition	-0.12	0.05	-0.14	0.00	70	-0.12	0.06	85
Health care	-0.03	0.00	-0.05	0.00	100	-0.03	0.00	100
Reproduction	-0.12	0.19	-0.45	0.27	60	-0.12	0.12	70
Housing	-0.05	0.14	-0.05	0.05	70	-0.03	0.00	70
In/output animals	-0.34	0.41	-0.14	0.09	20	-0.09	0.03	20
Prices	-0.42	0.20	0.00	0.09	35	-0.09	0.09	45
AVERAGE	-0.18	0.17	-0.18	0.13	60	-0.10	0.07	61

B. Results* of comparative analysis

Area	CHESS		Expert familiar farms			Expert unfamiliar farms		
	Neg	Pos	Neg	Pos	PTA	Neg	Pos	PTA
Overall impression	-0.14	0.22	-0.45	0.59	50	-0.30	0.33	70
Nutrition	-0.12	0.08	-0.14	0.09	75	-0.18	0.15	75
Health care	-0.04	0.02	-0.18	0.00	75	-0.06	0.06	85
Reproduction	-0.09	0.16	-0.23	0.41	75	-0.18	0.27	65
Housing	-0.05	0.07	-0.14	0.05	70	-0.09	0.00	70
In/output animals	-0.21	0.41	-0.23	0.27	50	-0.18	0.15	40
Prices	-0.20	0.30	-0.18	0.27	40	-0.27	0.21	50
AVERAGE	-0.12	0.18	-0.22	0.24	62	-0.18	0.17	65

Table 5. Continued.

C. Results* of comparative trend analysis

Area	CHESS		Expert familiar farms			Expert unfamiliar farms		
	Neg	Pos	Neg	Pos	PTA	Neg	Pos	PTA
Overall impression	-0.12	0.22	-0.05	0.05	30	-0.09	0.12	45
Nutrition	-0.09	0.09	0.00	0.00	70	-0.03	0.03	70
Health care	-0.09	0.04	-0.05	0.00	70	-0.03	0.00	70
Reproduction	-0.08	0.15	0.00	0.09	65	-0.03	0.12	70
Housing	-0.08	0.07	0.00	0.00	65	0.00	0.00	65
In/output animals	-0.13	0.46	0.00	0.00	35	-0.03	0.03	35
Prices	-0.23	0.18	0.00	0.05	55	0.00	0.00	55
AVERAGE	-0.12	0.17	-0.01	0.03	56	-0.03	0.04	59

* Neg: average CF of negative conclusions in an area (weaknesses)
Pos: average CF of positive conclusions in an area (strengths)
PTA: Percent Test Agreement between CHESS and expert (see text)

The test agreement between CHESS and experts on familiar and unfamiliar farms are presented in Table 6, in which the CF-classes per area and per type of analysis are summarized. It can be calculated that the percent test agreement between CHESS and experts on their familiar farms was 59% ((199+36+14)/420) which can be broken down into test agreements of 60% for trend analysis, 62% for comparative analysis, and 56% for comparative trend analysis. The percent test agreement between CHESS and the expert on unfamiliar farms was slightly higher: 61% in general, and 61% for trend analysis, 65% for comparative analysis, and 59% for comparative trend analysis.

In the field CHESS should be used as a system for early detecting of problems or opportunities and it is therefore important that CHESS does not overlook the early stages of such changes. Table 6 provides a basis for calculating the occurrence of such errors. CHESS may be considered to have overlooked strengths or weakness if the CF given by CHESS fell into class A while the corresponding CF given by the experts fell into the classes B or C. The percent mis-classification errors turned out to be 4% ((17+1)/420; see Table 6.A) between CHESS and experts on their familiar farms and 4% ((18+0)/420) between CHESS and experts on unfamiliar farms. Both these mis-classification errors were mainly found in the reproduction area and in the comparative farm analysis.

Looking to the summations (n) of the classes in Table 6, there were considerable differences between CHESS and the experts. CHESS classified 52% of the CF values into class A, 28% in class B and 20% in class C, with small differences between the three types of analysis. The experts, however, classified about 74%, 21%, and 5% in the classes A, B, and C respectively, with considerable differences between the types of analysis. Only the results of the comparative analysis were comparable with CHESS. This also indicates that the experts mainly concentrated on comparative analysis.

The average CF of experts on their familiar farms were higher than either the CF of CHESS and CF of experts on unfamiliar farms, which may be expected because more information was available for analysis.

Table 6. Results of CHESS versus experts on familiar and unfamiliar farms

A. Familiar farms

		Expert			
	class*	A	B	C	n
CHESS	A	199**	17	1	217
	B	75	36	8	119
	C	44	26	14	84
	n	318	79	23	420

B. Unfamiliar farms

		Expert			
	class*	A	B	C	n
CHESS	A	199**	18	0	217
	B	64	48	7	119
	C	39	34	11	84
	n	302	100	18	420

* class A: no positive (strengths) or negative (weaknesses) conclusions
class B: positive/negative conclusions with low certainty (CF ≤ |0.34|)
class C: positive/negative conclusions with high certainty (CF ≥ |0.35|)

** numbers refer to the total number of conclusions involved

3.3.2. Expert versus expert

So far, it has been assumed that the two domain experts used in validation of CHESS had the same level of expertise. The individual farm analysis results of the experts can be compared with each other in two ways. Firstly, the results of the analysis on their familiar farms can be compared with the results of the analysis on the unfamiliar farms. This would indicate the value of familiarity with the farms being analyzed. The second possibility is to compare the results of one expert with the results of the other, which gains insight into differences between the experts. The results of these two comparisons are given in Table 7.

Table 7. Results of the comparison of the experts

A. Expert on familiar farms versus unfamiliar farms

		Expert unfamiliar farms			
	class*	A	B	C	n
Expert familiar farms	A	275**	38	6	319
	B	24	47	6	77
	C	1	14	19	24
	n	300	99	21	420

B. Expert I versus expert II

		Expert II			
	class*	A	B	C	n
Expert I	A	275**	39	6	320
	B	23	47	12	82
	C	1	8	9	18
	n	299	94	27	420

* class A: no positive (strengths) or negative (weaknesses) conclusions
class B: positive/negative conclusions with low certainty (CF ≤ |0.34|)
class C: positive/negative conclusions with high certainty (CF ≥ |0.35|)
** numbers refer to the total number of conclusions involved

The percent test agreement in farm analysis results between the expert on familiar and unfamiliar farms, and between the two experts was 79% ((275+47+9)/420; see Tables 7.A and 7.B). Because only two experts are used for validation of CHESS, the agreement between the expert on familiar farms and the expert on unfamiliar farms necessarily equaled the agreement between the two experts. The experts on familiar farms and on unfamiliar farms totally disagreed in 2% of the cases ((1+6)/420; see classes (C,A) and (A,C) in Table 7.A)). This disagreement cannot be traced back to any particular area. Experts on their familiar farms tended to mention fewer elements (Table 7.A), but those mentioned were connected with higher certainty factors (Table 5).

The total disagreement between the two experts was 2%, which also cannot be traced back to a certain area. Small differences between the experts included that expert I tended to slightly over-estimate strengths and weaknesses, compared to expert II. It can be concluded that only minor differences occurred between the two experts, and therefore, the assumption that the two experts used the same level of expertise cannot be rejected.

4. DISCUSSION AND OUTLOOK

In the foregoing, the term "system" is often used. In this study, a system is defined as an assembly of components, connected together in an organized way, which one wants to consider as a whole (Walker, 1988). Modelling of a physical or real-world system on a computer is called a "computer system". Therefore, concepts of validating models can be applied to validating systems, although most literature on validation concerns validation of models. For the sake of clarity the term "physical system" is omitted in this study by using the terms "real world", "real environment", or "reality".

For practical reasons, only ten farms and two experts were used for the field test of CHESS. Therefore, major attention should be focused on the validation method, and not on the individual test results, which give nevertheless an indication of the quality of CHESS-recommendations within the test. Further validation is necessary in a larger field test using more farms and more experts to gain insight into the behavior of the system on a larger scale before it can be used in the field.

A further problem of the field test described above has been the lack of suitable data for the three types of analysis. Instead of using quarterly farm data for trend analysis of three previous years, only the data for the four quarters of 1987 and first three quarters of 1988 could be provided by the information system on the farms. In addition for comparative and comparative trend analysis, individual farm data from a group of similar farms must be available in time if they are to be used for early tracing of problems. In general, external farm data are provided with such a time lag that they cannot be used in individual farm analysis for early tracing of problems.

Due to the nature of the ES in CHESS, it is hard to define a "gold standard" against which the system's performance can be compared. In validating CHESS a method has been developed for testing the system as a whole. Comparison with reality is not possible and, therefore, the system has been validated by comparing the system's answers with answers of the two domain experts. Two problems may arise with this method of validation. First, it may be hard to obtain a match between the conclusions of the system and the expert. Different experts may disagree on certain details or both the system and the expert may be wrong. Second, a domain expert is not always right, even in his area of expertise, which may result in a false sense of correctness with this method of validation (Gaultney, 1985). Other possible causes of differences between system and expert conclusions may include: (1) a certain part of the system is not completely right, and (2) the experts used additional knowledge, which is not yet incorporated into the system. So, it is difficult to determine under what situations or conditions differences between system and expert answers should result in modifying the system.

As could be expected, there were only small differences between the performance of the two experts used in validating CHESS. There were also only small differences in farm analysis between results of experts on their familiar farms and on unfamiliar farms, although the experts in the first case could use more information related to the farm, farmer, and production circumstances. Based on the present field test, it can be concluded that this additional information has little value for identifying the strengths and weaknesses on individual farms, but enabled the experts to specify these strong and weak elements with a higher degree of certainty.

This study suggests methods by which the performance of a system containing both DSS and ES can be validated. The validation of ES in particular is difficult and no methods can be found in the literature. As use of DSS and ES, or of ES integrated into DSS, increases in future, it is essential to develop and use scientifically sound methods for validating their performance.

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CHAPTER 4

An application of stochastic dynamic programming to support sow replacement decisions

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ABSTRACT

In this chapter a stochastic dynamic programming model on the personal computer is introduced to determine the economic optimal replacement policy in swine breeding herds. This optimal policy maximizes the present value of expected annual net returns from sows present in the herd and from subsequent replacement gilts over a given planning horizon. However, realistic dynamic programming replacement models include a large number of state and decision variables. A major issue in the underlying study has been how to cope with the resulting curse of dimensionality. An alternative dynamic programming model structure has been developed and evaluated. Furthermore, a sensitivity analysis has been carried out to achieve insight into possibilities for further reduction of the model size. In this process, the quality of the results obtained are weighed against the amount of computation time needed to carry out the calculations.

1. INTRODUCTION

Swine breeding farmers are frequently faced with the difficult problem of determining the optimal time at which to cull sows from their herds. In the Netherlands, for instance, on average 43-55% of the sows are replaced annually (Baltussen *et al.*, 1988). Simultaneous consideration of several biological and economic variables and relationships is critical to the accuracy of sow evaluations for replacement purposes. Decisions to replace sows are mainly based on economic rather than biological considerations. The farmer expects a higher profit when replacing the sow. The complexity and regularity of culling decisions suggest the use of formal computer decision models.

At any time a replacement could be made is called a "decision moment". A sequence of decisions is called a "policy", and a policy which is most profitable is called an "optimal policy". Usually, determining the optimal replacement policy for sows is treated as a tactical decision problem. The tactical decisions involved are made within the tactical or medium term planning, which is carried out within the scope set by the strategic planning (Huirne, 1990). Knowledge of the optimal replacement policy and the influence of changes in biological and economic variables on it may assist the swine breeding farmer in taking these day-to-day management decisions.

White (1959) made one of the first published suggestions for applying dynamic programming (DP) to solving on-farm decisions. He determined optimal replacement policies for flocks of laying hens, and drew attention to the scope of the DP-technique for application to other types of livestock. Throsby (1964) also noted that DP might be successfully applied in determining optimal replacement policies for continually operating livestock enterprises. In developing any DP-model for determining the optimal replacement policy, two aspects are to be considered. The first aspect concerns the size of the model. Constructing realistic DP-models provides for several problems, such as memory problems and computation time problems. Hence, the choice of the model structure and the biological and economic variables involved are very important. The second aspect relates to use of the model. For the model to be frequently used and widely accepted, it must be user-friendly and suitable for use in the field and, therefore, available on a personal computer (PC). The user data and model output need to be designed to suit users with few computing skills.

In this chapter, the outline of a stochastic DP-model on a PC for analysis of sow culling decisions is presented. In particular, the choice of the model structure and the variables used are described and discussed. The model runs with default values, but all data can easily be adjusted to represent a specific herd or a different region. Moreover, major results obtained from both the basic situation and from the sensitivity analysis, and the potential use of the model for further research and application are discussed. The detailed zootechnical-economic aspects and results of the model are described by Huirne *et al.* (1990).

2. THE SOW REPLACEMENT MODEL

2.1. General aspects

The stochastic DP-technique (value function iteration) is used (1) to quantify the benefits of increased lifespan in swine breeding herds, and (2) to determine the optimal replacement policy for individual sows with poor productive and/or reproductive performance. The stochastic formulation makes it possible to account for other, more involuntary reasons of culling (e.g. disease, death) and for variation in (re-)production traits, including litter size. Given the production level at the present stage, the distribution of production levels at the next stage can be defined taking into account the sow's repeatability of production (Van Arendonk, 1985). As mentioned before, the model has been constructed on a personal computer. It runs with default values, but allows the user to enter data for all variables considered, and therefore, can easily be adjusted to individual farm conditions worldwide.

The quality of the replacement sow is assumed to be unrelated to the characteristics of the particular sow being replaced. Hence, at any given point in time replacement sows all have the same expected quality. In this way, any sow present in the herd is compared to a common standard, and a listing of the relative merit of each sow can be effected (Smith, 1973). The replacement model does not take into account improvement in the basic genetic capacity of sows to produce piglets over a period of time.

2.2. Description of the sow replacement model

Dynamic programming is used to determine the replacement policy that maximizes the present value of expected net returns over a given planning horizon. Computation begins at the final stage in the planning horizon (T) and proceeds backwards in time, stage by stage, until the first stage is reached (Bellman, 1957). The value of the sows at the end of the planning horizon is set equal to their slaughter value. At the beginning of the planning horizon, the model starts with a new replacement gilt. At each stage, the present value of net returns when keeping the sow until the end of that stage and following an optimal policy during the remainder of the planning horizon (decision "Keep"), is compared with the present value of net returns when the sow is replaced immediately (decision "Replace"). The maximum present value of expected net returns during the remainder of the planning horizon under an optimal replacement policy ($V_t(X_t)$), given the initial state X_t of the sow at the beginning of stage t, is calculated using the following equations (all model components are explained and discussed in the next sections):

$$V_t(X_t) = S(X_t) \qquad (t = T) \qquad (1)$$

$$V_t(X_t) = (1\text{-}PI(X_t))\left\{\text{Maximum}\left[VK_t(X_t),\ VR_t(X_t)\right]\right\} + PI(X_t)\left\{S(X_t) + VG_{tT} - FL\right\} \qquad (2 \leq t \leq T\text{-}1) \qquad (2)$$

$$V_t(X_t) = -CG + (1\text{-}PI(X_t))\left\{\text{Maximum}\left[VK_t(X_t),\ VR_t(X_t)\right]\right\} + PI(X_t)\left\{S(X_t) + VG_{tT} - FL\right\} \qquad (t = 1) \qquad (3)$$

where:

$$VK_t(X_t) = \delta\Big[PC(X_t)\textstyle\sum_{n=4}^{16}\Big\{PL(X_t,n)(G_t(X_t,n) + V_{t+\alpha}(T_t(X_t,n)))\Big\}$$
$$+ (1\text{-}PC(X_t))\Big\{G_t(X_t,0) + V_{t+\beta}(T_t(X_t,0))\Big\}\Big] \qquad (4)$$

$$VR_t(X_t) = S(X_t) + VG_{tT} \qquad (5)$$

where:

X_t = vector representing the state of the sow at stage t ($1 \leq t \leq T$);

$V_t(X_t)$ = the maximum present value of expected net returns during the remainder of the planning horizon under optimal replacement policy given the initial state of the sow at the beginning of stage t;

$VK_t(X_t)$ = present value of expected net returns given the current state of the sow, the decision to keep her at stage t, and an optimal replacement policy during the remainder of the planning horizon;

$VR_t(X_t)$ = present value of expected net returns given the current state of the sow, the decision to replace her by a replacement gilt at stage t, and an optimal replacement policy during the remainder of the planning horizon;

VG_{tT} = present value of expected net returns from stage t until the end of the planning horizon T for a replacement gilt under an optimal policy (which is determined by iteration: see next sections);

$PI(X_t)$ = marginal probability of involuntary disposal at the beginning of stage t of a sow in state X_t;

$PC(X_t)$ = marginal probability of conception at the beginning of stage t of a non-pregnant sow in state X_t;

$PL(X_t,n)$ = probability of a litter size of n pigs born alive at stage $t+\alpha$ for a pregnant sow in state X_t ($4 \leq n \leq 16$);

α = number of days between two successive successful breedings (on average 153 days);

$G_t(X_t,n)$ = net returns between stage t and stage $t+\alpha$ for a sow kept in X_t with a litter size of n pigs born alive at stage $t+\alpha$. For $n = 0$ it represents the net returns between stage t and stage $t+\beta$ for a sow kept in X_t having failed to conceive and coming on heat again at stage $t+\beta$;

β = number of days between an unsuccessful breeding and the corresponding rebreeding (on average 21 days);

$T_t(X_t,n)$ = transformation function: if a sow in state X_t gives a litter size of n pigs born alive at stage $t+\alpha$, she then comes in state $X_{t+\alpha} = T_t(X_t,n)$. For $n = 0$ it represents a sow in state X_t which does not conceive, showing heat again at stage $t+\beta$ and coming in state $X_{t+\beta} = T_t(X_t,0)$;

$S(X_t)$ = slaughter value of a sow in state X_t;

FL = additional financial loss associated with involuntary disposal of a sow;

CG = cost of a replacement gilt;

δ = discount factor.

After the optimal lifespan of a sow has been calculated in this way, the model can be used to determine the total extra profit to be expected from keeping her until that optimum, compared with immediate replacement, taking into account the risk of involuntary disposal of retained sows. This total extra profit, called Retention Pay-Off (RPO), can be calculated for each individual sow as follows:

$$RPO(X_t) = VK_t(X_t) - VR_t(X_t) \qquad (6)$$

where:

$RPO(X_t)$ = Retention Pay-Off given the initial state X_t of the sow at stage t;

The other symbols have been previously defined.

The above formulation of the stochastic DP-model is rather complex. Therefore, the characteristic elements of the model are discussed in the next sections.

2.3. Stage and state variables

Sows are described by the state vector (X_t) consisting of four variables: parity number (i_t), production level in previous parity (j_t), production level in the next to previous parity (k_t), and the number of unsuccessful breedings in the present parity (l_t). The term "parity" is synonymous with a sow's production cycle. Parity number corresponds with the number of realized litters of a sow, and a breeding by insemination or service. Possible values of the state variables are summarized in Table 1.

Table 1. Possible values of the state variables

Number of sow production cycles	State variable* i_t	j_t	k_t	l_t	Total number of possible states
1	0	-	-	0-3	4
2	1	4-16	-	0-3	52
3-10	2-9	4-16	4-16	0-3	5408
11**	10	4-16	4-16	0	169
				TOTAL	5633

* for explanation: see text

** all sows are replaced immediately after the 10th litter (10th parity): at the beginning of the 11th production cycle

According to Table 1, parity number can vary from 0 to 10. A gilt has parity number 0. After having produced her first litter, she comes in parity 1. Because the maximum parity number considered is 10, all sows that have produced 10 litters are replaced at the beginning of parity 10. Litter size in the previous two parities varies between 4 and 16 pigs born alive, whereas the number of unsuccessful breedings per parity varies between 0 and 3. Thus, if a sow does not become pregnant from the fourth service, she will be replaced in any case. The state variables are defined in such a way that it is possible to take decisions at daily intervals. Average values for the user-defined biological sow performance, including the length of gestation and lactation period, result in a total length of the planning horizon T of 1580 days (4.3 years). Due to these biological reasons, however, each stage does not correspond with a decision moment. Stages are considered only if they contain relevant states. Given the planning horizon, the model thus jumps from decision moment (stage) to decision moment in the sow's life. At each state, two possible decisions can be taken: (1) to keep the sow till the next state, or (2) to replace her immediately. Thus, the decision variable consist of two components: "Keep" or "Replace".

The actual structure of the DP-model runs parallel to the sow's life. The model starts its first state and stage with a (replacement) gilt coming on heat for the first time. It ends with a sow having just ended the lactation period of her 10th litter. The states (in particular i_t) and stages in the model are therefore closely interwoven, which results in an acceptable size of the PC-model, considering memory request and computation time.

2.4. Economic components

The economic criterion for sow replacement decisions can be described as follows: a particular sow should be kept in the herd as long as the present value of the marginal net returns from keeping her until the next parity is higher than the present value of the lifetime average net returns from a replacement gilt (Huirne *et al.*, 1988). This income potential of the gilt cannot be realized as long as the sow is kept in the herd. It can, therefore, be interpreted as the opportunity cost of postponed replacement (Dijkhuizen *et al.*, 1986).

Variable returns included in the replacement model are the value of the piglets born alive, and the slaughter value of culled sows. Major variable costs are the cost of replacement gilts, and the feed costs. Costs and returns that can be assumed to be the same for all sows at a given point in time can be ignored when taking replacement decisions. Examples are the fixed costs of housing, equipment, land, and most of the labour.

The slaughter value of sows is calculated per kilogram live weight. The additional financial loss associated with involuntary disposal is built into the model to account for losses associated with disposal such as decrease in slaughter value, and cost of veterinary treatment prior to disposal. To account for time preference of costs and returns, the discount factor in the DP-model is calculated using a real annual interest rate of 4.5%. The price of a replacement gilt is taken to be Dfl. 400 (400 Dutch guilders) at an age of 180 days.

2.5. Probabilities

In the model, the optimal replacement policy is determined, taking into account the risk of involuntary disposal of retained sows. The marginal probabilities of involuntary disposal are based on the parity number of the sow (i_t). As indicated before, involuntary disposal is caused by such reasons as sickness/accidents, bad maternal characteristics, lameness/leg weakness, and death of the sow (Dijkhuizen *et al.*, 1989).

The marginal probabilities of conception are dependent on the number of unsuccessful breedings in a certain parity (l_t). These probabilities are based on Bisperink (1979).

The probability of litter size is based on both the parity specific litter size (dependent on i_t) and the relative level of past piglet production of the sow. The latter effect is calculated from the litter size in the 2 previous parities of the sow (j_t, k_t), compared to the parity specific litter size in these 2 parities, using the repeatability of litter size. Although repeatability of litter size in individual sows is commonly accepted to be low, it is significantly above zero (Van der Steen, 1984[a]; Dijkhuizen *et al.*, 1986; Huirne *et al.*, 1988). For each sow, a mean litter size is therefore determined consisting of two elements: the parity specific litter size and this relative level of past performance. The probability of litter size is then calculated according to a normal distribution from the mean litter size of the sow and the corresponding standard deviation (Huirne *et al.*, 1988).

2.6. Dynamic programming runs

In order to keep the size of the model within an acceptable range, the model structure is such that the states and stages are closely related, as mentioned previously. If the option to replace a certain sow is considered at stage t, a new replacement gilt as such is not introduced into the model, but the optimal present value of expected annual net returns from stage t until the end of the planning horizon T (calculated as an annuity) for that replacement gilt (VG_{tT}) is used in the calculations. For the first run of the model, a standard value for net returns per sow per year of the replacement gilt must be entered by the user. Due to the special structure of the model, the result of the first run is, among others, a new value for net returns per sow per year. The new value can then be used as input value for the second run, and so on. If the difference between the input value and the resulting output value for net returns per sow per year is below a small user-defined pre-specified limit, all model results are assumed to be stable and further runs are not necessary. Basically, the limit equals 0.1% of the output value for net returns per sow per year. The protocol described above can be compared with a convergent iterative process over an infinite planning horizon. Due to this iterative process, the current model size is about 40 times as small as it normally would have been, and therefore, the sow replacement can be solved on the PC in this case.

2.7. Description of the sample farm

To illustrate the protocol described above, the model is used to optimize the replacement policy on a sample farm, representing a typical Dutch swine breeding farm. To gain more insight into the level of management on this farm, some major production and price parameters are presented in Table 2.

Table 2. Some major production and price parameters of the typical Dutch swine breeding sample farm

Variable	Value
Duration of lactation period (days)	30
Duration of gestation period (days)	115
Duration of sow's oestrus cycle (days)	21
Values for an average (3rd parity) sow:	
- expected litter size (pigs born alive)	10.8
- piglet mortality rate (%)	14.5
- expected number of pigs sold per litter	9.2
- probability of involuntary disposal (%)	10.0
Price sow feed (Dfl. per 100 kg)	50.0
Price pig feed (Dfl. per 100 kg)	82.5
Market price per feeder pig sold (Dfl.)	115
Cost of a replacement gilt at first breeding (Dfl.)	506
Slaughter value for an average (3rd parity) sow (Dfl.)	489

As shown in Table 2, only some major parameter values for an average sow are given, i.e. a sow in her third parity. Her expected litter size is 10.8 pigs born alive. This, together with a piglet mortality rate of 14.5%, results in 9.2 pigs raised and sold per litter. The cost of a replacement gilt is slightly higher than the slaughter value of a third parity sow. For a more detailed description of the herd characteristics, reference is made to Huirne *et al.* (1990).

3. RESULTS

Besides understanding the basic results obtained for the sample farm it is also important to gain insight into the behaviour of the model and the sensitivity of the results. Therefore the basic results are presented first in the next section and then the effects of changed conditions in some major model characteristics are described.

3.1. Basic results for the sample farm

The optimal replacement policy for the sample farm results in an average herd life of 5.5 parities (Table 3). The annual replacement rate emerges as 41.7%. Of all sow present in the herd, 17.8% are replaced voluntarily because of insufficient productive and reproductive characteristics, being 43% of all replaced animals. The average number of feeder pigs sold per sow per year is 20.9, which is the result of 2.31 litters per sow per year, a litter size of 10.6 pigs born alive, and a piglet mortality rate of 14.7% (Table 3). The optimal policy results in an annuity of the present value of expected net returns per sow per year of Dfl. 852 and in a herd in which 50.88% of the sows are in parities 0, 1 or 2. The effects of changes in the standard deviations of litter size, which are also presented in Table 3, are discussed in the section below.

In Table 4, average Retention Pay-Off (RPO) values are presented. These are given for retained sows only, at the moment of first breeding in each of the parities. As shown in Table 4, the RPO is highest for young sows. At the end of parity 9, the RPO is not yet below zero, and hence the maximum economic life of sows of average production is (slightly) more than 9 parities.

Table 3. Basic results for the sample farm and effects of changes (-50% and +50%) in the standard deviations of litter size

Variable	Low* (-50%)	Basic	High* (+50%)
Average herd life (parities)	5.8	5.5	5.3
Annual voluntary replacement rate (%)	15.3	17.8	20.1
Annual involuntary replacement rate (%)	24.6	23.9	23.3
Annual replacement rate (%)	39.9	41.7	43.4
Litters per sow per year	2.31	2.31	2.31
Litter size (pigs born alive)	10.6	10.6	10.6
Piglet mortality rate (%)	14.7	14.7	14.7
Number of pigs sold per litter	9.1	9.0	9.0
Number of pigs sold per sow per year	21.0	20.9	20.9
Maximum present value of expected net returns per sow per year (Dfl.)	852	852	842
Sows in parities 0-2 (%)	48.67	50.88	52.91

* for standard deviation used: see text

Table 4. Average retention Pay-Off (RPO) for retained sows at the moments of first breeding

Parity number	0	1	2	3	4	5	6	7	8	9
RPO (Dfl.)	116	172	163	134	98	74	60	48	39	27

3.2. Effects of the number of dynamic programming runs

As mentioned previously, a series of dynamic programming runs (DP-runs) are necessary to obtain stabilized results. The effects of the number of DP-runs on the central processor time, on the maximum present value of expected net returns, on the herd structure (percent sows in parities 0-2), and on the percent inaccuracy are outlined in Table 5. Percent inaccuracy is defined as percent disagreement between the optimal replacement decisions after each run and the optimal decisions after fourteen runs.

Table 5. Effects of the number of DP-runs on the central processor time, on the annual net returns, on the optimal herd structure, and on percent inaccuracy

Number of runs	Central processor time**	Annual net returns* (Dfl.)			Percent sows in parities 0-2	Percent inaccuracy***
		Input	Output	Difference (%)		
1	0'25"	800	826	3.166	46.56	5.38
2	0'50"	826	839	1.505	48.45	3.43
3	1'14"	839	845	0.750	49.63	1.65
4	1'39"	845	848	0.386	50.42	0.68
5	2'04"	848	850	0.202	50.61	0.42
6	2'29"	850	851	0.106	50.81	0.17
7	2'54"	851	852	0.056	50.88	0.07
8	3'19"	852	852	0.030	50.88	0.07
9	3'44"	852	852	0.016	50.93	0.02
10	4'08"	852	852	0.008	50.94	0.01
11	4'34"	852	852	0.004	50.94	0.00
12	4'58"	852	852	0.002	50.95	0.00
13	5'23"	852	852	0.001	50.95	0.00
14	5'48"	852	852	0.001	50.95	0.00

* maximum present value of expected net returns per sow per year

** central processor time to solve the DP-recurrence relations using an IBM compatible personal computer with an 80286 micro-processor and an 80287 math-processor (x'y" means x minutes and y seconds)

*** percent disagreement between the optimal replacement decisions after each run and the optimal decisions after 14 runs

Increasing the number of DP-runs results in more precise model outcomes, which is reflected in an important decrease in the difference between input and output value for net returns per year and in small inaccuracies. On the other hand, central processing time to solve the DP-recurrence relations increases considerably from 0'25" (25 seconds) for one run to 5'48" (5 minutes and 48 seconds) for fourteen runs. The total time for performing the calculations can be determined by including an additional 4'24", which is a fixed amount of time for carrying out other essential calculations, and for writing data-files to and reading from (hard) disk.

Increasing the number of runs also influences the herd structure (Table 5). Herd structure is very sensitive to a low number of runs. For example, the percentage of sows in parities 0-2 increases from 46.56% after one run to 50.88% after seven runs. An increase in the number of runs after the ninth run hardly affects the herd structure and percent inaccuracy, and it may be assumed that a stable sow herd is then obtained.

The decision to carry out all model calculations run after run until the difference between input and output value of net returns is smaller than 0.1%, mentioned previously, has been based on these developments in total computation time, net returns per year, herd structure, and percent inaccuracy. In the basic situation seven runs are necessary to reach this limit of 0.1% (Table 5), which takes in total 7'18". This equals 2'45" for central processor time added to 4'24" for fixed amount of computation time. After seven runs the inaccuracy emerges as 0.07%, which is an acceptable value.

3.3. Effects of variation in litter size

The standard deviations in litter size used in the model were calculated by Van der Steen (1984[b]). The basic standard deviation in litter size is 2.780 pigs born alive if no previous information is used, 2.724 if information of one previous litter is used, and 2.706 if litter size of two previous litters is used. Major effects of an increase and a decrease in the standard deviations of 50% are summarized in Table 3.

A reduction in standard deviation results in a higher average herd life (5.8 parities). Low standard deviations in litter size result in fewer underproductive sows, causing a lower annual voluntary replacement rate (15.3% versus 17.8%) and also a lower total replacement rate (39.9% versus 41.7%). Lower total sow replacement results in a longer average herd life. This effect is also illustrated in Figure 1. As the sows become older, so the involuntary replacement rate slightly increases from 23.9% in the basic situation to 24.6% in the situation with low standard deviations. For increasing standard deviations, the opposite is true. Changes in standard deviations do not greatly influence herd averages for litters per sow per year, litter size, piglet mortality and number of pigs sold (Table 3).

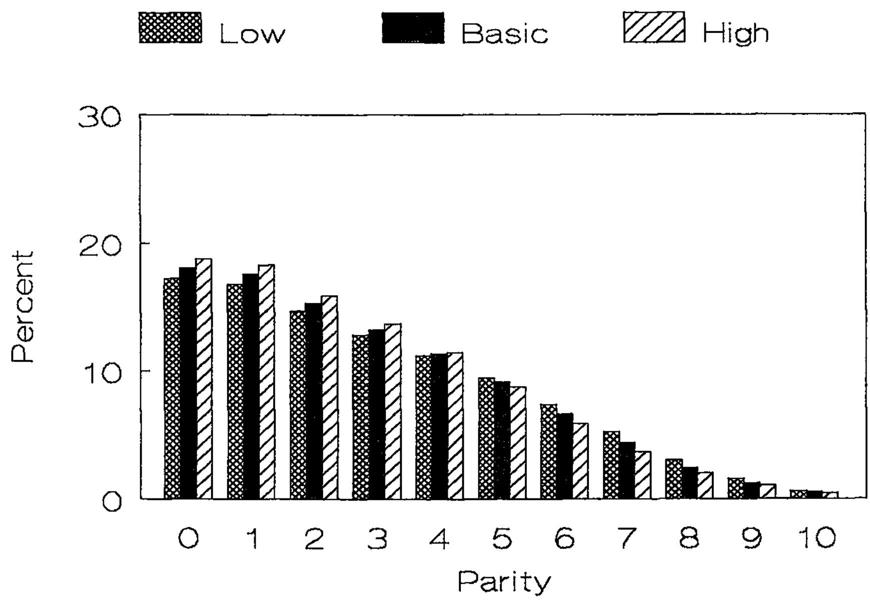

Figure 1. Effects of changes (-50% (low) and +50% (high)) in the standard deviations of litter size on the herd structure (percentage of sows in each parity; see text)

3.4. Effects of maximum number of breedings allowed per parity

As mentioned previously, the size and structure of the DP-model is an important matter to be considered in developing the computer model. The basic version of the model includes a maximum of 4 breedings allowed per parity. The total number of possible states, therefore, equals 5633 (Table 1). The effects of a reduction in the maximum number of breedings allowed per parity on major results is summarized in Table 6.

If the maximum number of breedings allowed per parity is reduced from 4 to 1, the total number of possible states in the DP-model decreases from 5633 to 1535, respectively. This results in much shorter central processor time. On the other hand, decreasing the maximum number of breedings allowed has a considerable negative effect on the net returns per year, on the herd structure, and on percent inaccuracy. From the latter point of view, the reduction of model size from 4 to 3 breedings allowed may be considered, but a reduction to 1 or 2 can certainly not be recommended.

In the model, the maximum number of breedings allowed equals four. Additional calculations show that in the basic situation only 1.36% of the sows present in the herd should receive a service or insemination for their 4th breeding. This results in 0.82% of the sows being replaced because they do not become pregnant in the 4th breeding. For this reason, a 5th breeding is not considered in the model.

Table 6. Effects of the maximum number of breedings allowed per parity on the size of the DP-model, on the central processor time, on the annual net returns, on the optimal herd structure, and on percent inaccuracy

Max. number of breedings allowed	Number of possible states	Central processor time*	Annual net returns** (Dfl.)	Percent sows in parities 0-2	Percent inaccuracy***
1	1535	0'44"	821	61.26	15.17
2	2901	1'28"	848	53.04	3.60
3	4267	2'11"	851	51.24	0.66
4 (Basic)	5633****	2'54"	852	50.88	0.00

* central processor time to solve the DP-recurrence relations using an IBM-compatible personal computer with an 80286 micro-processor and an 80287 math-processor (x'y" means x minutes and y seconds)
** maximum present value of expected net returns per sow per day
*** percent disagreement between the optimal replacement decisions in each situation and the optimal decisions in the basic situation
**** see also Table 1

3.5. Effects of maximum number of parities considered

Besides reducing the maximum number of breedings allowed, the size and structure of the DP-model can be diminished by taking fewer parities into account. To be able to calculate the optimal replacement policy, the model must include at least 3 parities. The effects of reducing the maximum number of parities from 10 (basic situation) to 3 are given in Table 7.

As can be seen in Table 7, decreasing the maximum number of parities considered in the model results in decreasing net returns per sow day, and in increasing percentages of sows in parities 0-2. At the same time, the size of the model is reduced from 5633 possible states if maximal 10 parities are considered to 901 states if maximal 3 parities are considered. The smaller size of the model results in less central processor time: from 2'11" (9 parities) to 0'11" (3 parities), and in increasing model inaccuracies: from 1.02% (9 parities) to 42.82% (3 parities). Especially in the case of a low number of parities (i.e. 3 to 7 parities), the results obtained are inaccurate. The total time required for determining the optimal replacement policy proves to be 7'18" for 5633 possible states and 4'35" for a model size of 901 states. If the user of the model is not interested in results of highest accuracy, he may consider reducing the model structure from maximal 10 parities to 9 or 8 parities. However, the computation time saved is relatively small.

An 11th parity is not included in the model because, in the basic situation, only 0.48% of the sows present in the herd produce 10 litters. Therefore, an 11th parity is not worth consideration in the model, although the development of the RPO-values in Table 4 might suggest it.

Table 7. Effects of the maximum number of parities considered on the size of the DP-model, on the central processor time, on the annual net returns, on the optimal herd structure, and on percent inaccuracy

Max. number of parities considered	Number of possible states	Central processor time*	Annual net returns** (Dfl.)	Percent sows in parities 0-2	Percent inaccuracy***
3	901	0'11"	778	80.05	42.82
4	1577	0'20"	817	68.27	30.09
5	2253	0'39"	836	61.10	19.82
6	2929	1'03"	844	56.80	12.27
7	3605	1'19"	848	53.92	6.55
8	4281	1'53"	851	52.51	3.35
9	4957	2'11"	851	51.34	1.02
10 (Basic)	5633****	2'54"	852	50.88	0.00

* central processor time to solve the DP-recurrence relations using an IBM-compatible personal computer with an 80286 micro-processor and an 80287 math-processor (x'y" means x minutes and y seconds)

** maximum present value of expected net returns per sow per year

*** percent disagreement between the optimal replacement decisions in each situation and the optimal decisions in the basic situation

**** see also Table 1

4. DISCUSSION AND OUTLOOK

DP has the advantage of being an adequate tool for optimization of an objective function over a planning horizon (Johnston, 1965). The planning horizon can be short, but easily be extended. Moreover, DP is able to handle certain problem characteristics that other methods can hardly deal with. Two of these characteristics are nonlinear objective function coefficients and probabilistic or stochastic outcomes (Throsby, 1964; Dannenbring and Starr, 1981). DP is, therefore, a suitable technique for taking into account biological variation in animals. Examples of biological variation incorporated in the underlying DP-model are the stochastic variables of involuntary disposal, the moment of conception, and litter size. The effects of variation in litter size have been summarized in Table 3 and Figure 1. Furthermore, DP problems are particularly suited to being solved by the computer. Whilst the DP algorithm typically requires a vast number of calculations, the computer model is usually concise because of the repetitive nature of the algorithm (Kennedy, 1981).

DP has a major disadvantage in coping with the complexity which occurs if the state or decision vectors possess a large number of components. Important criteria for evaluating the success of a DP procedure in solving a problem are the amount of computation time and computer memory required. The fact that problems often have to be simplified leads to another criterion: the closeness of the DP solution to the solution of the original problem. There are many practical problems, including sow replacement problems, for which the computation requirements of the standard algorithm would be unduly burdensome. This is also called "the curse of dimensionality" (Bellman and Dreyfus, 1962; Johnston, 1965; Kennedy, 1986). In complex cases it is necessary to consider whether there are alternative methods of applying the logic of DP to solve the problem. Kennedy (1986) mentions some alternative methods. In the underlying study an alternative DP structure is used. This alternative structure of the sow replacement model includes, as mentioned previously, states and stages which are closely interwoven, resulting in an acceptable size of the model. In doing so, the curse of dimensionality can be skilfully avoided. Further reduction of the model size, however, may not be recommended because more inaccurate results are then obtained. For instance, reducing the maximum number of breedings allowed per parity from 4 to 1 will result in an inaccuracy of 15.17%. This changes corresponds with a herd structure of 61.26% of the sows in parities 0, 1 or 2 instead of 50.88% in the basic situation (Table 6). Similar effects are obtained if a reduction in the maximum number of parities is being considered (Table 7).

An important issue in determining the precision of the results and the time needed for completing the calculations is the number of DP runs carried out. As a result of the optimal replacement policy, the present value of expected net returns per sow per year equals Dfl. 852 (Table 5). If fewer than 5 runs are carried out, net returns differ considerably from this optimal value, and higher inaccuracies are obtained. On the other hand, the computation time increases with increasing number of runs. In general, a choice must be made between obtaining high quality results combined with high computation time, and less accurate results combined with low computation time. This consideration resulted in a compromise: the basic calculations are repeated until the difference between the input and output value for present value of expected net returns per year is less than 0.1%.

In practice, the different uses that might be made of the DP-model can be considered from the standpoint of (White, 1959): (1) the researcher, (2) the extension worker, and (3) the individual decision maker. Here, it is not implied that there are three separate and distinct models of solving the sow replacement model. The researcher may be concerned with the stability of the replacement policy, i.e. how changes in assumptions and input parameters might affect the results of the model. The stability of the optimal policy might also be determined. The extension worker's interest is in providing general recommendation as to a sow replacement policy. For this reason, research is needed to provide these recommendations, for instance by deriving concise heuristic rules from all optimal decisions available. The model has great potential applicability to the cases of individual decision makers. If they supply their own expectation or estimates of model input parameters, the model will generate the optimal replacement policy as it applies to their particular cases. Therefore, it is the intention to incorporate the model into an existing computer system named CHESS (Computerized Herd Evaluation System for Sows), which can serve as a support system to all potential users mentioned above.

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CHAPTER 5

Economic optimization of sow replacement decisions on the personal computer by method of stochastic dynamic programming

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ABSTRACT

A stochastic dynamic programming model is designed on the personal computer to determine the economic optimal replacement policy in swine breeding herds. This optimal policy maximizes the present value of expected annual net returns over a specified planning horizon from sows present in the herd and subsequent replacement gilts. The model also calculates the total extra profit to be expected from attempting to retain an individual sow until her optimal lifespan and not replacing her immediately. This total extra profit is an economic index which makes it possible to rank sows within a herd on future profitability and, therefore, can be used as a management guide in culling decisions. Given the probabilities of involuntary replacement, the optimal replacement policy results in an average herd life of 5.5 parities. The corresponding present value of expected annual net returns per sow equals Dfl. 852. The optimal economic life of average producing sows emerges as 9 parities. The optimal policy is most sensitive to the difference between the cost of a replacement gilt and the slaughter value of culled sows. Moreover, conception rates have a considerable effect on net returns, replacement rate, and average herd life. All data can easily be adjusted to represent a specific herd or different region of the world.

1. INTRODUCTION

The decision whether to keep or replace sows is a frequent and an important one. Replacement decisions were mainly concerned in statistical causes (Dagorn and Aumaitre, 1979; Kroes and Van Male, 1979; Te Brake, 1986). Insufficient productive and reproductive performance account for more than half of the annual replacements (Dijkhuizen *et al.*, 1989). This type of culling decisions is particularly based on economic considerations. Usually, a sow is replaced not because she is no longer able to produce in a biological sense, but because a replacement gilt is expected to yield more (Dijkhuizen *et al.*, 1986; Huirne *et al.*, 1988). Most of the published work on optimizing this type of decision has dealt with dairy cattle (Zeddies, 1972; Renkema and Stelwagen, 1979; Gartner, 1981; Dijkhuizen *et al.*, 1985; Van Arendonk, 1985; Kristensen, 1987). Although on average 43-55% of the sows are replaced annually (Van der Steen, 1984; Singh, 1986; Baltussen *et al.*, 1988; Dijkhuizen *et al.*, 1989), surprisingly little research has been done on the economics of culling in swine breeding herds. Dijkhuizen *et al.* (1986) have developed a model on the personal computer (PC), in which sow replacement decisions are optimized using the marginal net revenue approach. Huirne *et al.* (1988) described a more detailed research model for mainframe computers in which dynamic programming was used to optimize the culling policy of sows taking into account the biological variation in litter size only.

In this chapter, a detailed stochastic dynamic programming model on the PC for the analysis of sow culling decisions is described and applied. In particular, the zootechnical and economic aspects of the model structure and the variables used are outlined. Influences of changes in production, reproduction, and price parameters on the optimal policy are established. Furthermore, an economic index is calculated to be used as a culling guide for individual sows within a herd. An extensive description of the dynamic programming (DP) technique, and the major mathematical aspects of the DP-model are presented in detail by Huirne *et al.* (1990[b]).

2. MATERIALS AND METHODS

2.1. Dynamic programming model

Dynamic programming (DP) is a mathematical technique, which involves the optimization of multi-stage decision processes (Bellman, 1957). It basically divides a given problem into stages or subproblems and then solves the subproblems sequentially until the initial problem is finally solved.

Stochastic dynamic programming includes one or more stochastic variables, and is used in this chapter to determine the optimal replacement policy for sows, which may be considered a multi-stage decision problem. The objective is to maximize the present value of expected net returns over a specified planning horizon. This requires finding the optimal keep-replace decision for all kinds of sows that are likely to occupy the process when evaluated. Optimization starts at the end of the planning horizon ($t = T$) at which the value of all sows is set equal to their slaughter value. The process then continues backwards until the first stage ($t = 1$) of the planning horizon is reached. At each stage the present value of expected net returns associated with keeping the sow until the next stage and then following an optimal policy during the remainder of the planning horizon (decision "Keep") is compared with the present value of expected net returns when the sow is replaced immediately by a replacement gilt (decision "Replace").

In the model, sows are described by a state vector (X_t) with components consisting of (Huirne *et al.*, 1990[b]): parity number (i_t), production level in previous parity (j_t), production level in the next to previous parity (k_t), and the number of unsuccessful breedings in the current parity (l_t). Parity number varies from 0 to 10, production level from 4 to 16 pigs born alive, and the number of unsuccessful breedings from 0 to 3. In this way, the state vector results in a total of 5633 possible states or types of sows. Given the initial state of the sow, the optimal decision and the corresponding maximum present value of expected net returns from stage t until the final but one stage (T - 1) of the planning horizon ($V_t(X_t)$) is calculated using the following equations (Huirne *et al.*, 1990[b]; all model components are explained in the next sections):

$$V_t(X_t) = (1-PI(X_t))\left\{\text{Maximum}\left[VK_t(X_t),\ VR_t(X_t)\right]\right\} + PI(X_t)\left\{S(X_t) + VG_{tT} - FL\right\} \qquad (2 \le t \le T\text{-}1) \qquad (1)$$

$$V_t(X_t) = -CG + (1-PI(X_t))\left\{\text{Maximum}\left[VK_t(X_t),\ VR_t(X_t)\right]\right\} + PI(X_t)\left\{S(X_t) + VG_{tT} - FL\right\} \qquad (t = 1) \qquad (2)$$

where:

X_t = vector representing the state of the sow at stage t ($1 \le t \le T$);

$V_t(X_t)$ = the maximum present value of expected net returns during the remainder of the planning horizon under optimal replacement policy given the initial state of the sow at the beginning of stage t;

$VK_t(X_t)$ = present value of expected net returns given the current state of the sow, the decision to keep her at stage t, and an optimal replacement policy during the remainder of the planning horizon;

$VR_t(X_t)$ = present value of expected net returns given the current state of the sow, the decision to replace her by a replacement gilt at stage t, and an optimal replacement policy during the remainder of the planning horizon;

VG_{tT} = present value of expected net returns from stage t until the end of the planning horizon T for a replacement gilt under an optimal policy;

$PI(X_t)$ = marginal probability of involuntary disposal at the beginning of stage t of a sow in state X_t;

$S(X_t)$ = slaughter value of a sow in state X_t;
FL = additional financial loss associated with involuntary disposal of a sow;
CG = cost of a replacement gilt.

The model also calculates the total extra profit to be expected from keeping a sow until her optimum, compared with immediate replacement. This total extra profit, called Retention Pay-Off (RPO), is calculated as follows (Huirne *et al.*, 1990[b]):

$$RPO(X_t) = VK_t(X_t) - VR_t(X_t) \qquad (3)$$

where:
$RPO(X_t)$ = Retention Pay-Off given the initial state X_t of the sow at stage t;
The other symbols have been previously defined.

Major zootechnical-economic characteristics of the DP-model are discussed in the next sections. As mentioned before, mathematical aspects of the model are described in Huirne *et al.* (1990[b]).

2.2. Basic production and price components

As the expected future profitability of sows is not affected by fixed costs, the net returns considered in the DP-model are only based on those returns and costs which differ between the various parity numbers of sows: feeder pig sales, slaughter value, and feed costs. The model also accounts for the cost of replacement gilts, and other variable costs. Feeder pig sales, feed costs, and other variable costs are incorporated into the net return variable. The slaughter value of removed sows ($S(X_t)$) and the cost of replacement gilts (CG) are treated separately. The DP-model calculates with default values for input variables, but allows the user to enter other data for all variables considered, and therefore can easily be adjusted to individual farm conditions.

Piglet production of a sow is dependent on parity number. Average litter size in each parity is given in Table 1. Litter size is highest in parities 4-6. First parity sows produce a relatively low number of pigs born alive. Piglet mortality rate before weaning, however, is lowest in parities 1-4. Piglet mortality rate after weaning is taken to be 1.5%. This results in the parity-specific number of feeder pigs sold, which is also presented in

Table 1. This figure reaches its maximum during the fourth and fifth parity and declines afterwards. The market price of feeder pigs equals Dfl. 115 (115 Dutch guilders) per pig sold at 23.5 kg of live weight. The model calculates with insemination costs of Dfl. 27.50 per breeding.

Table 1. Parity-specific default input values used in the DP-model

Parity number	Pigs born alive	Piglet mortality rate* (%)	Feeder pigs sold	Live weight sow** (kg)	Slaughter value sow (Dfl.)	Involuntary disposal*** (%)
0	-	-	-	140	392	-
1	9.6	13.0	8.2	160	416	11
2	10.3	12.0	8.9	175	455	11
3	10.8	13.0	9.2	188	489	10
4	11.1	13.0	9.5	196	510	12
5	11.2	14.0	9.5	200	520	14
6	11.1	14.0	9.4	200	520	16
7	11.0	14.0	9.3	200	520	18
8	10.9	15.0	9.1	200	520	20
9	10.8	15.0	9.0	200	520	21
10	10.7	15.0	8.9	200	520	23

* piglet mortality rate before weaning; mortality rate after weaning: 1.5%

** at the average time of removal of about 1 month after weaning

*** probability of involuntary disposal at the beginning of each parity (see text)

The sow and pig feed used can be characterized as standard ration, with an average energy content. The default values for daily feed consumption of pregnant gilts and pregnant sows are the same. The daily amount for lactating sows equals 1.0% of their live weight and additionally 0.4 kg per piglet. Piglets use up to feeder pig weight (23.5 kg live weight) in total 30 kg of feed. The price of the ration for pregnant animals and open sows is Dfl. 50 (per 100 kg), and for lactating animals Dfl. 52.5. The price of feedstuffs for replacement gilts is somewhat higher (Dfl. 62.5 per 100 kg), and piglet feed is the most expensive (Dfl. 82.5 per 100 kg).

Furthermore, other variable costs include Dfl. 0.75 per day for sows (e.g. for interest, veterinary costs, car, telephone, water, electricity), and Dfl. 0.50 per day for gilts up to the first breeding (e.g. for infertility risk). Other variable costs per feeder pig sold are Dfl. 5, to take into account such items as costs of castration and transportation.

The live weight of sows and the corresponding slaughter value of sows ($S(X_t)$) increase with an increasing parity number (Table 1). The price per kg live weight is highest for young sows (Dfl. 2.80 versus Dfl. 2.60 for old sows).

The cost of a replacement gilt (CG) used in the DP-model equals Dfl. 400 at an age of 180 days. This corresponds with Dfl. 506 at an age of 230 days, at which she first comes on heat and, thus, when she can first become pregnant.

If the sow becomes pregnant after the first service, her production cycle takes 153 days. After the gestation period of 115 days, she has a lactation period of 30 days. Then, 8 days are needed for the interval from weaning till first breeding. The length of the sow's oestrus cycle equals 21 days.

2.3. Probabilities

Three types of probabilities are used in the model: (1) marginal probability of involuntary disposal, (2) marginal probability of conception, and (3) probability of a specific litter size.

Marginal probability of involuntary disposal ($PI(X_t)$), which counts for all disposals except for disposals caused by insufficient productive and reproductive performance, depends on parity number (Table 1), and has been based on Dijkhuizen *et al.* (1986), Huirne *et al.* (1988), and Dijkhuizen *et al.* (1989). Marginal probability of involuntary disposal is lowest for parity 3 (10%) and increases to 23% for parity 10.

Marginal probabilities of conception are influenced by the number of unsuccessful breedings in a certain parity. The following marginal probabilities for conception are used 85% (1st breeding), 65% (2nd breeding), 50% (3rd breeding), and 40% (4th breeding). These figures are mainly based on Bisperink (1979) and Te Brake (1986).

Both the parity-specific litter size (Table 1) and the relative historical litter sizes are used to calculate the probability of litter size in future parities. In predicting litter size, the number of pigs born alive from up to 2 previous parities are used, and compared with the corresponding parity-specific litter size. The DP-model needs the repeatability of litter size to determine the expected litter size in future parities. Generally, the repeatability of litter size in individual sows is low, but significantly above zero (Van der Steen, 1984; Knap, 1985). The following default repeatability factors for litter size have been incorporated into the model: 0.20 between 2 successive parities, and 0.15 with 1 parity in between. These factors have been based on Van der Steen (1984), Knap (1985) and Huirne *et al.* (1988). After the expected or mean litter size has been determined in this way, the model calculates the probability of litter size for each possible sow from her mean litter size and the corresponding standard deviation of litter size according to a normal distribution (Huirne *et al.*, 1990[b]).

2.4. Other components

The additional financial loss associated with involuntary disposal (FL) is built into the model to account for losses associated with disposal such as decrease in slaughter value, and costs of veterinary treatment prior to disposal.

The discount factor is calculated in the DP-model to account for time preference of costs and returns using a real annual interest rate of 4.5%.

The planning horizon in the basic situation is taken to be 30 years (11060 days). This corresponds with 7 times the maximal lifespan of a sow in the model. By using this planning horizon stable results are obtained (Huirne *et al.*, 1990[b]).

3. RESULTS

Results for the basic (default) situation are presented first in the next section. To achieve insight into the behaviour of the model and the sensitivity of the results, the effects of variation in major price and production variables, in probabilities of involuntary disposal, and in conception rates have been analyzed. Results obtained from this sensitivity analysis are subsequently described.

3.1. Basic situation

Given the default input values for the DP-model, presented in the previous sections, the optimal replacement decisions result in an optimal average herd life of 5.5 parities. Annual voluntary replacement rate for insufficient production and reproduction accounts for 17.8%, which is 42.7% of the total annual replacement rate. The number of pigs sold per sow per year is 20.9, which is a combined result of litters per sow per year (2.31), litter size (10.6 pigs born alive) and piglet mortality rate (13.2% pre-weaning and 1.5% after weaning). In the optimal situation the maximum present value of expected net returns per sow per year, calculated as an annuity, equals Dfl. 852.

Table 2. Average production limits per parity and breeding below which replacement is optimal (number of pigs born alive)

Parity	Breeding 1	Breeding 2	Breeding 3	Breeding 4
1	4.0*	4.0*	7.0	9.0
2	5.0	6.0	8.2	10.4
3	6.1	7.4	9.9	12.2
4	7.3	9.3	11.7	14.2
5	8.7	10.7	13.2	15.3
6	9.3	11.7	14.1	16.0*
7	10.4	12.4	15.1	16.0*
8	10.6	13.1	15.6	16.0*
9	11.4	14.4	16.0*	16.0*
10	16.0**			

* lower and upper limit of litter size in the model (4 and 16 pigs born alive, respectively)

** in the model, all sows are replaced immediately after the 10th litter

The production level or limit below which voluntary replacement is optimal is given in Table 2. The production limits are highly dependent on parity number and the number of breedings in each parity. The production limits generally increase with increasing parity number and also with an increasing number of breedings, as might be expected. All first parity sows may from an economic point of view have at least 2 breedings. The production limits for a third and fourth breeding, should these sows still not be pregnant, depend on their first litter size: 7.0 and 9.0 pigs born alive, respectively (Table 2). A fourth breeding is hardly ever optimal for sows in parities 6-9 (the limits equal 16), and sows in parity 9 should even never receive a third breeding. As previously described, all sows are replaced immediately after the 10th litter (at the beginning of parity 10); hence the production limit equals 16. These production limits result in an increasing marginal voluntary replacement rate across parities. The marginal voluntary replacement rate emerges as 2.6% at the beginning of parity 0, reaching its minimum at the beginning of parity 1 (2.0%), and then increasing from 2.5% (parity 2) to 34.9% (parity 9). The marginal voluntary replacement rate per parity, together with the marginal involuntary replacement rate, is outlined in Figure 1.

In Table 3 the average number of breedings allowed per parity and litter size is presented. This figure is calculated at the beginning of each parity (at the moment of first breeding).

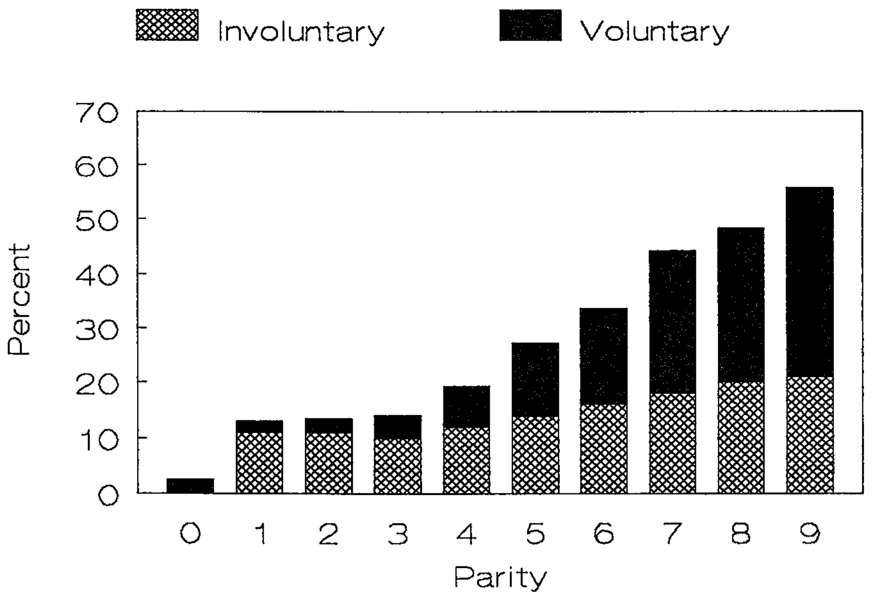

Figure 1. Marginal voluntary and involuntary replacement rates per parity

Table 3. Average number of breedings allowed per litter size at the beginning of each parity*

Parity number	Litter size (number of pigs born alive)												
	4	5	6	7	8	9	10	11	12	13	14	15	16
0	3.0**												
1	2.0	2.0	2.0	3.0	3.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
2	0.4	1.4	1.8	2.3	2.7	2.9	3.0	3.0	4.0	4.0	4.0	4.0	4.0
3	0.1	0.3	0.7	1.6	2.0	2.4	2.7	2.9	3.0	3.0	3.0	4.0	4.0
4	0.0	0.0	0.2	0.4	1.0	1.6	1.9	2.4	2.7	2.9	3.0	3.0	3.0
5	0.0	0.0	0.0	0.1	0.2	0.7	1.3	1.7	2.1	2.5	2.8	3.0	3.0
6	0.0	0.0	0.0	0.0	0.1	0.3	0.9	1.3	1.7	2.1	2.4	2.8	3.0
7	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.8	1.3	1.7	2.1	2.3	2.7
8	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.6	1.1	1.4	1.9	2.1	2.4
9	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.7	1.0	1.3	1.5	1.9
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0***

* weighted average based on litter size in next to previous parity
** not based on litter size
*** all sows are replaced immediately after the 10th litter

As shown in Table 3, the average number of breedings allowed is highly influenced by parity number and litter size. The number of breedings allowed increases with decreasing parity number and increasing number of pigs born alive. For gilts (parity 0), for instance, 3 breedings are allowed, which means 1 (first) breeding and 2 re-breedings. First parity sows with a litter size below 7 pigs born alive may have a maximum of 2 breedings, sows with a litter size of 7 or 8 pigs 3 breedings, and sows with a litter size above 8 pigs born alive 4 breedings. Fourth parity sows having produced a litter of 4 or 5 pigs born alive are allowed to have on average no further breedings, and therefore, should be replaced. This outcome (no further breedings allowed) applies to an increasing number of sows: to sows with litter sizes of 4-6 pigs born alive (parity 5) to 4-9 (parity 9). The best sows in parity 9 may even have on average a maximum of 1.9 breedings (16 pigs born alive; Table 3).

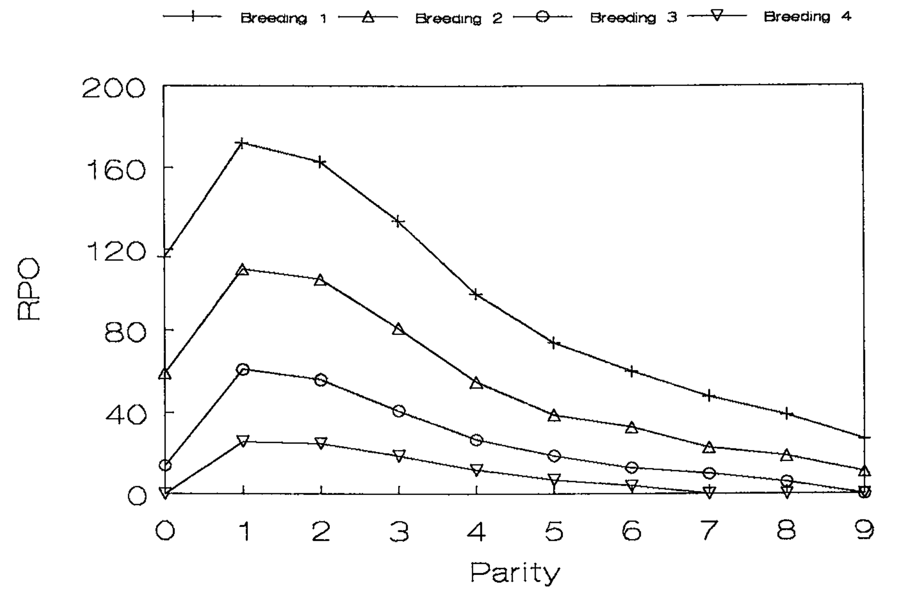

Figure 2. Average Retention Pay-Off (RPO) for retained sows at the beginning of each parity and breeding (Dfl.)

Table 4. Alternative price and production levels and their influences on the annual net returns, the voluntary replacement rate, and on the average herd life (between brackets the deviation from the basic situation)

Variable and value			Annual net returns per sow* (Dfl.)		Annual voluntary replacement rate (%)		Average herd life (parities)	
Feeder pig price (Dfl.):								
- low	92	(-20%)	385	(-467)	17.3	(-0.5)	5.6	(+0.1)
- basic	115		852		17.8		5.5	
- high	138	(+20%)	1318	(+466)	18.2	(+0.4)	5.5	(0.0)
Feed price (Dfl./100 kg):								
- low	****	(-20%)	1073	(+221)	19.1	(+1.3)	5.4	(-0.1)
- basic	**		852		17.8		5.5	
- high	****	(+20%)	631	(-221)	17.2	(-0.6)	5.6	(+0.1)
Slaughter value (Dfl.):								
- low	****	(-20%)	807	(-45)	12.6	(-5.2)	6.1	(+0.6)
- basic	***		852		17.8		5.5	
- high	****	(+20%)	904	(+52)	29.1	(+11.3)	4.6	(-0.9)
Cost replacement gilt (Dfl.):								
- low	320	(-20%)	898	(+46)	33.0	(+15.2)	4.3	(-1.2)
- basic	400		852		17.8		5.5	
- high	480	(+20%)	811	(-41)	13.2	(-4.6)	6.0	(+0.5)
Pre-weaning mortality rate (%):								
- low	****	(-20%)	901	(+49)	17.4	(-0.4)	5.6	(+0.1)
- basic	***		852		17.8		5.5	
- high	****	(+20%)	802	(-50)	18.5	(+0.7)	5.5	(0.0)
Litter size (number of pigs born alive):								
- low	****	(-20%)	550	(-302)	19.2	(+1.4)	5.4	(-0.1)
- basic	***		852		17.8		5.5	
- high	****	(+20%)	1142	(+290)	17.4	(-0.4)	5.6	(+0.1)
Interval weaning-first breeding (days):								
- low	6.4	(-20%)	869	(+17)	18.0	(+0.2)	5.5	(0.0)
- basic	8.0		852		17.8		5.5	
- high	9.6	(+20%)	834	(-18)	17.6	(-0.2)	5.6	(+0.1)
Length of lactation period (days):								
- low	24	(-20%)	938	(+86)	18.5	(+0.7)	5.5	(0.0)
- basic	30		852		17.8		5.5	
- high	36	(+20%)	772	(-80)	17.8	(0.0)	5.5	(0.0)

* maximum present value of expected net returns per sow per year

** basic values: see text

*** basic values are summarized in Table 1

**** alternative values for "low" and "high" are calculated from the basic values summarized in Table 1 and in the text

Average Retention Pay-Off (RPO) values are presented in Figure 2. These are given for retained sows only, at the beginning of each parity and breeding. As previously mentioned, RPO values are dependent on both individual parity-specific litter size and farrowing interval, and therefore, RPO values differ considerably between sows. As shown in Figure 2, the RPO is highest for young sows. At the time of a gilt's first breeding, the RPO is Dfl. 116, which means that keeping the sow is more profitable than replacing her immediately, as might be expected. This single RPO value represents the difference between the slaughter value of the gilt and the costs of a replacement gilt. The RPO value of the gilt decreases by Dfl. 57 if she does not become pregnant from the first service. The RPO value falls below zero at the beginning of the fourth breeding, and hence the maximum number of breedings of gilts is three (Figure 2).

3.2. Variation in price and production variables

Alternative price and production levels and the results of the optimal replacement policies are summarized in Table 4. The annual present value of expected net returns per sow is sensitive to changes in feeder pig prices, feed prices, and litter size. It is not highly influenced by the slaughter value of culled sows, the cost of replacement gilts, pre-weaning mortality, and the interval between weaning and first breeding.

In contrast to the annual net returns, the optimal replacement policy is most sensitive to the difference between the cost of a replacement gilt and the slaughter value of culled sows. A reduction of this difference results in a higher rate of voluntary replacement and in a shorter average herd life (Table 4). The optimal replacement policy is not very sensitive to changes in feeder pig price, feed price, pre-weaning mortality, the interval between weaning and first breeding, and the duration of the lactation period. These variables affect the sow which can be replaced, as well as the replacement gilt.

3.3. Variation in involuntary disposal

The consequences of a proportional increase and decrease of 20% in the marginal probabilities of involuntary disposal for the replacement policy and annual net returns per sow are given in Table 5. A 20% decrease in marginal probability of involuntary disposal, in the case of voluntary disposal, results in increasing annual net returns per sow of Dfl. 7, and also in an increase in annual voluntary replacement rate (2.5%) and in the average herd life (0.3 parities). A 20% increase in involuntary disposal leads to a Dfl. 8 reduction in annual net returns per sow, to a reduction in the annual voluntary replacement rate of 2.2%, and also to an increase in the average herd life of 0.2 parities.

If all sows are kept until they have to be replaced involuntarily the annual net returns per sow decreases by Dfl. 10, and the average herd life increases from 5.5 to 6.5 parities. If the probability of involuntary disposal decreases by 20%, and voluntary disposal is not permitted, the annual net returns per sow increases relatively less (Dfl. 5 versus Dfl. 7) and the average herd life relatively more (0.6 versus 0.3 parities) than in the case where there was voluntary disposal. Reducing the involuntary disposal, therefore, is more profitable when part of this reduction is used for increasing voluntary replacement, instead of for increasing the average herd life only (Table 5).

Table 5. Alternative probabilities of involuntary disposal and their influence on the annual net returns, the voluntary replacement rate, and on the average herd life for a situation with and without voluntary disposal (between brackets the deviation from the basic situations)

Probability of involuntary disposal (%)			Annual net returns per sow* (Dfl.)		Annual voluntary replacement rate (%)		Average herd life (parities)	
With voluntary disposal:								
- low	***	(-20%)	859	(+7)	20.3	(+2.5)	5.8	(+0.3)
- basic	**		852		17.8		5.5	
- high	***	(+20%)	844	(-8)	15.6	(-2.2)	5.3	(-0.2)
No voluntary disposal:								
- low	***	(-20%)	847	(+5)	10.5****	(+1.9)	7.1	(+0.6)
- basic	**		842		8.6****		6.5	
- high	***	(+20%)	836	(-6)	7.1****	(-1.5)	6.1	(-0.4)

* maximum present value of expected net returns per sow per year

** basic values are summarized in Table 1

*** alternative values for "low" and "high" are calculated from the basic values summarized in Table 1

**** disposal for exceeding the maximum number of breedings allowed (4) and the maximum number of parities considered

3.4. Variation in conception rates

A proportional increase in the marginal conception rates of 10% and 18% leads to higher annual net returns per sow (Dfl. 43 and Dfl. 71, respectively), while a reduction of 10% and 20% results in much lower annual net returns: Dfl. 53 and Dfl. 118, respectively (Table 6). Increasing conception rates result in decreasing annual voluntary replacement rates and, therefore, in a higher average herd life, as might be expected. On the other hand, the economic and technical parameters are also very sensitive to decreasing conception rates. A 20% decrease in the conception rates causes, relative to the basic situation, a 7.6% increase in the annual replacement rate and a reduction in average herd life of 0.8 parities. Additional calculations show that the costs of an extra open day equals Dfl. 4.43 in the optimal situation.

Table 6 also demonstrates the non-linear effects of changing conception rates. A reduction of these rates has a more than proportional effect on the economic and technical parameters, while an increase results in a less than proportional effect.

Table 6. Alternative conception rates and their influence on the annual net returns, the voluntary replacement rate, and on the average herd life (between brackets the deviation from the basic situation)

Conception rates (%)			Annual net returns per sow* (Dfl.)		Annual voluntary replacement rate (%)		Average herd life (parities)	
- very low	68/52/40/32**	(-20%)	734	(-118)	25.4	(+7.6)	4.7	(-0.8)
- low	77/59/45/36	(-10%)	799	(-53)	21.2	(+3.4)	5.2	(-0.3)
- basic	85/65/50/40		852		17.8		5.5	
- high	94/72/55/44	(+10%)	895	(+43)	16.0	(-1.8)	5.8	(+0.3)
- very high	100/--/--/--	(+18%)	923	(+71)	15.2	(-2.6)	5.9	(+0.4)

* maximum present value of expected net returns per sow per year
** conception rates for 1st, 2nd, 3rd, and 4th breeding respectively

3.5. Variation in other variables

As mentioned before, the repeatability factors used for predicting future litter sizes are in the basic situation: 0.20 between 2 successive parities and 0.15 with 1 parity in between. The effects of doubling these factors reduces the average herd life from 5.5 to 4.9 parities, combined with an increase of the annual voluntary replacement rate from 17.8% to 24.6%. The annual net returns per sow increases from Dfl. 852 to Dfl. 868. This is understandable, since future litter sizes of sows can be predicted more precisely using the higher repeatability factor. This results in an early moment of replacement for under-productive sows and in a later moment for sows with good productive performance. Therefore, the RPO values of sows present in the herd are considerably higher compared to the basic situation (Figure 2). This effect is also reflected in the average number of breedings allowed per parity and breeding. Compared to the basic values in Table 6, high repeatability factors result in a relatively low number of breedings allowed for sows which produce a low number of pigs born alive, while it is economically optimal to inseminate the better sows more often.

Additional calculations show that, if there is no time preference of costs and returns (the real annual interest rate equals 0%), the expected net returns per sow per year would rise from Dfl. 852 to Dfl. 905. The other economic and technical parameters, however, are hardly affected, including the RPO values, production limits below which replacement is optimal, and number of breedings allowed. In the case of a discount factor based on a real annual interest rate of 9%, the expected net returns per sow are reduced to Dfl. 802 per year. The economic and technical parameters are hardly influenced either in this situation. Therefore, changing real annual interest rates (and thus discount factors) only have a minor impact on the optimal replacement decisions.

4. DISCUSSION AND OUTLOOK

Income per sow per year depends in particular on feeder pig price, feed prices and litter size. However, changes in these three factors do not greatly affect the optimal replacement policy (Table 4). This may be explained by realizing that the expected net returns of both the sows present in the herd and the replacement gilts are affected. On the contrary, the optimal replacement policy is much more sensitive to changes in the cost of a replacement gilt and in the slaughter value of culled sows. The smaller the difference between these two variables, the higher the voluntary replacement rate, which is in agreement with previous findings in cattle (Van Arendonk, 1985; Kristensen, 1987) and swine (Dijkhuizen *et al.*, 1986; Huirne *et al.*, 1988).

Dynamic programming is a flexible mathematical technique for determining the optimal replacement decisions for sows. Major advantages of dynamic programming include the fact that variation in, and repeatability of traits can be accounted for. Both the risk that high-producing sows may have a low future piglet production, and the risk that a sow may be replaced by a low-productive replacement gilt can, therefore, be taken into account. However, the dynamic programming model easily becomes very large. This results in a high memory request and high computation costs. In the underlying study, the size of the DP-model is kept within an acceptable range by taking into account a maximum of 10 parities and a maximum of 4 breedings per parity for each sow. These limitations hardly influence the outcomes, as investigated elsewhere (Huirne *et al.*, 1990[b]). Moreover, the model uses the litter size of the previous 2 parities to predict future litter sizes of sows. Information of a third previous litter is not utilized because it has only a minor additional predicting value (Van der Steen, 1984; Huirne *et al.*, 1988). Genetic improvement is not considered in the model, but it can be incorporated very easily, as demonstrated by Van Arendonk (1985) and Kristensen (1987).

The calculated RPO values for individual sows can be a useful guide for taking replacement decisions (Figure 2). However, characteristics of each possible sow in the herd can be entered into the DP-model. The results obtained include the RPO value for that particular sow, and thus the optimal decision "keep" or "replace". In the case of (health) problems, the RPO value of a sow represents the maximum amount of money that economically may be spent in trying to return her to previous production levels. The RPO results calculated at the beginning of each parity agree to a great extent with those published by Bisperink (1979), Dijkhuizen *et al.* (1986), and Huirne *et al.* (1988). Nevertheless, the current DP-model calculates the RPO values not only per parity as such but per parity specified per breeding (see Figure 2). This therefore results in a more precise and valuable support of sow replacement decisions for the individual farmer.

The DP-model can be used to support sow replacement decisions in the field. Therefore, it is intended to incorporate the model into an existing computer system named CHESS (Computerized Herd Evaluation System for Sows), which can be used as a support system for sow replacement decisions-makers in the field such as individual farmers, veterinarians and extension workers (Huirne *et al.*, 1990[a]). In the model, sows are replaced because of insufficient productive and reproductive performance. However, a substantial amount of the replacements is due to other reasons. Dijkhuizen *et al.* (1989), for instance, found that sickness/accidents account for 16.0% of the culled sows, maternal characteristics for 13.9% and lameness/leg weakness for 10.5%. These culling reasons are classified in the current

DP-model as "involuntary disposal". Average values for these reasons have been incorporated into the marginal probability of involuntary disposal (Table 1). The repetitive nature of the DP-algorithm makes it almost impossible to include these culling reasons, as they are generally difficult to quantify. Further research is needed to study the possibilities of extending the DP-model with an expert system. Expert systems, which are described by Waterman (1986) as computer programs using expert knowledge to attain high levels of performance in a narrow problem area, are particularly suited to work with subjective and qualitative elements. As an expert system is a modelling of the human reasoning process, it gives the same advice as its human counterpart (Huirne, 1990). In the sow replacement area, the integration of the DP-model and an expert system may have the advantage of producing synergetic results. In addition to the results of the DP-model, the farmer may be supported by the expert system in taking culling decisions for sows with, for instance, poor maternal characteristics or leg weaknesses.

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CHAPTER 6

An economic expert system on the personal computer to support sow replacement decisions

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ABSTRACT

An expert system (ES) has been designed on the personal computer for the economic optimization of sow replacement decisions focusing on qualitative characteristics of a sow. These characteristics include lameness and leg weakness, mothering characteristics, and udder quality. The expert system is coupled with an existing stochastic dynamic programming model (DP-model), which determines the economically optimal replacement policy based on productive and reproductive sow performance. The reasoning process of the expert system is focused on three major elements: (1) clinical sow deviations, (2) deviations in number of pigs weaned per litter, in relation to (3) deviations in uniformity of the litter. Deviations of the first type always result in the advice to replace the sow with a replacement gilt. After deviations of the second and/or third type have been found, they are weighted economically by the ES. Using the results of the DP-model, the ES calculates an economic index which makes it possible to rank sows within the herd on future profitability. Therefore, the index can be used as a management guide in culling decisions. The method of acquiring the knowledge (rules of thumb, heuristics) for the ES involved direct interviews with a domain expert, in which real and example problems have been used. Formal validation results indicate a high correspondence between the system's ranking of 30 blind test scenarios with the rankings provided by both the domain expert and a second expert.

1. INTRODUCTION

Sow replacement decisions are important management decisions and have to be taken frequently. Culling decisions are usually based on economic considerations. Sows are usually not replaced because they are unable to produce in a biological sense, but because replacement gilts are expected to yield a higher return (Dijkhuizen *et al.*, 1986). To support culling decisions with respect to insufficient productive and reproductive performance, which accounts for more than half of the annual replacements under Dutch circumstances, a stochastic dynamic programming model (DP-model) implemented on the personal computer has been developed (Huirne *et al.*, 1990[a], 1990[b]). The DP-model determines the economically optimal replacement policy by maximizing the present value of expected annual net returns from sows present in the herd and from subsequent replacement gilts over a given planning horizon. In the DP-model, sows are characterized in terms of parity number, production level in previous parity, production level in the next to previous parity, and the number of unsuccessful breedings in the current parity. The model also calculates the total extra profit to be expected from trying to retain an individual sow until her optimal lifespan and not replacing her immediately. This total extra profit is called Retention Pay-Off (RPO) and can be used to rank sows within the herd on future profitability and, therefore, can be used as a management guide in culling decisions.

Sows are culled not only because of insufficient productive and reproductive performance but also because of more qualitative reasons such as lameness and leg weakness, mothering characteristics, and udder quality (Dijkhuizen *et al.*, 1989; Stein *et al.*, 1990). As dynamic programming only can handle quantitative parameters, the DP-model cannot take such qualitative characteristics into account directly. Therefore, in addition to the DP-model an expert system (ES) has been developed to generate optimal replacement decisions taking the more qualitative sow characteristics into account. An ES can generally be defined as a computer program using expert knowledge to attain high levels of performance in a narrow problem area (Waterman, 1986), and thus can be considered as a modelling of the human reasoning process, making the same decisions as its human counterpart (Huirne, 1990). The ES developed in this study is integrated into a decision support system (DSS) of which the DP-model is one of the components, by using the output of the DSS as input (see next section). A DSS can briefly be defined as an information system that assists decision making (Davis and Olson, 1985). The ES assesses the following qualitative sow characteristics: (1) lameness and leg weakness, (2) mothering characteristics, and (3) udder quality. This results into an "improvement" of the original RPO-value of the sow, which has been calculated by the DP-model previously. The new RPO obtained is considered to be a more complete management guide in culling decisions because it covers a greater part of reality. This concept for supporting sow replacement decisions includes some new (ES) features that enhance effectiveness of decision making, which have not been described in literature before. Both the DSS and the ES belong to the computer system CHESS (Computerized Herd Evaluation System for Sows). The part of CHESS that relates to culling decisions is called CHESS-RO (Replacement Optimization).

In this chapter, the outline of the ES on the personal computer to support sow replacement decisions by analyzing the qualitative sow characteristics is be presented. In particular, the veterinary and economic aspects of the ES structure and the variables used are described and discussed. Moreover, major results obtained and the outcome of the validation procedure of the system are presented. Finally, the potential use of the system is discussed.

2. GENERAL OUTLINE AND ARCHITECTURE OF THE SYSTEM

To be a flexible system suitable for use in the field, CHESS-RO has been designed to be used on an IBM-PC compatible computer under the MS-DOS operating system. The whole system is controlled by menu driven procedures. All system communication is transparent to the user and is done through the use of intermediate files. The architecture of CHESS-RO is depicted in Figure 1.

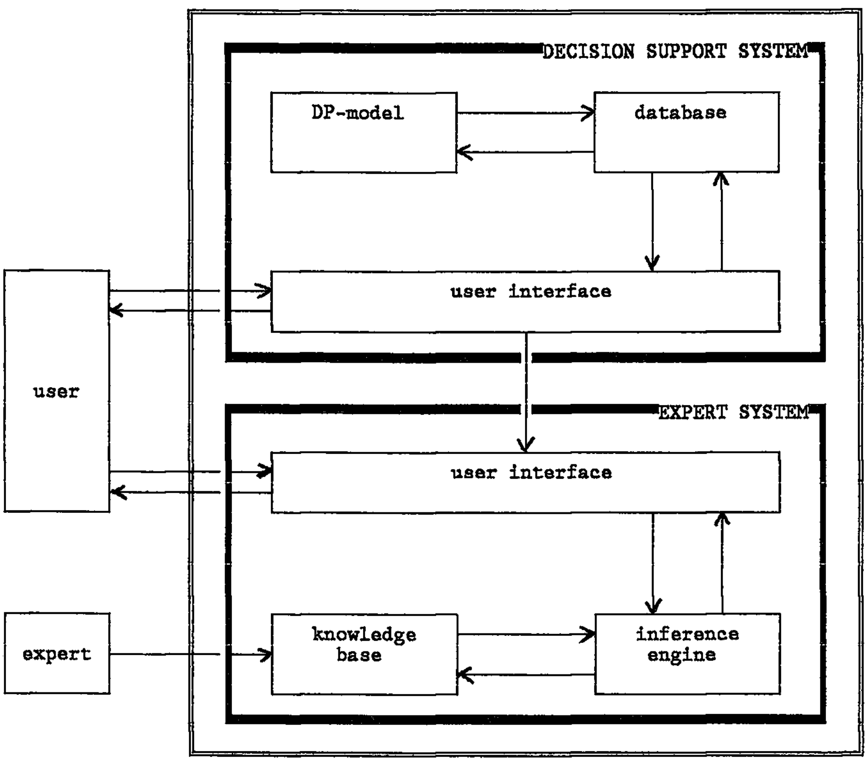

Figure 1. Architecture of CHESS-RO

As indicated in Figure 1, the system is composed of two major parts: the DSS and the ES. The following components exist in the DSS: (1) DP-model, (2) database, and (3) user interface. The DP-model has been introduced in the previous section, and can be described as an optimization algorithm for sow culling decisions based on productive and reproductive sow performance. Zootechnical and economic data needed to carry out the DP-calculations are stored in the database. The database is a collection of interrelated data organized in such a way that it corresponds to the needs and structure of the DP-model. Examples of input data stored in the database are: average (parity-specific) herd litter sizes and mortality rates, feeder pig sales, slaughter value of culled sows, daily feed intake and feed costs, cost of replacement gilts, and costs for veterinary treatment. The results of the DP-model, such as the optimal keep-replace decisions and the RPO-values, are also stored in the database. All communication between the DP-model and the user (entering farm data, for example) takes place through the user interface. The user interface is a component that allows user-friendly bidirectional communication between the system and its user (Turban, 1988). For a detailed description of the DP-model and results obtained, reference is made to Huirne *et al.* (1990[a], 1990[b]).

The second part of CHESS-RO is the ES. The ES was built using the LEVEL5 expert system shell (Information Builders, 1988), which is a complete ES stripped of its specific knowledge. It consists of the following components: (1) user interface, (2) inference engine, and (3) knowledge base. Just like the DP-model, the ES also has a user interface, which contains a language processor for easy, problem-oriented communications between the user and the computer. Through its user interface the ES also has access to the database of the DSS. In this way, zootechnical and economic farm data and the results of the DP-model can be used by the ES. The "brain" of the ES is the inference engine, also known as the control structure, containing general or standard problem solving and decision making knowledge (Turban, 1988). The inference engine processes the domain knowledge on sow replacement, which is located in the knowledge base, to reach (new) conclusions (Waterman, 1986). The third part of the ES is the knowledge base. The information in the knowledge base is everything necessary for understanding, formulating, and solving the sow replacement problem. It includes two basic elements: (1) facts, such as the problem situation and theory of the problem area, and (2) special heuristics or rules that direct the use of knowledge to solve the problems in the particular sow replacement domain. The process of extracting, structuring, and organizing knowledge (facts and special heuristics) from some source is generally called "knowledge acquisition" (Waterman, 1986). This should be done in such a way that it can be used in the ES. Usually, knowledge is derived from human expert(s).

In the next sections attention is paid to the knowledge acquisition activities carried out to derive the knowledge for the CHESS-RO expert system. Furthermore, the knowledge present in the knowledge base is described.

3. KNOWLEDGE ACQUISITION FOR THE EXPERT SYSTEM

Knowledge acquisition has been described previously as the extraction of knowledge from sources of expertise and its transfer to the knowledge base. In the underlying study, knowledge acquisition followed standard procedures. A veterinary expert in sow replacement decisions was identified. The expert has extensive teaching and consulting experience. During the entire time of developing the ES, the knowledge engineer, which is the person responsible for knowledge acquisition, worked closely with the domain expert. The standard procedures for knowledge acquisition followed were developed by Buchanan *et al.* (1983). These include the following five stages: (1) identification, (2) conceptualization, (3) formalization, (4) implementation, and (5) testing.

During the first, or identification, stage the knowledge engineer met with the expert to define the problem and to gain an initial understanding of it. The sow replacement problem based on qualitative characteristics has been broken down into subproblems (see next section), the resources (expert, popular and scientific literature) have been identified, and consistent terminology has been established.

The second (conceptualization) stage has been focused on finding concepts and relations to represent the sow replacement knowledge.

The third stage of knowledge acquisition is formalization, which can be described as designing a structure to organize the knowledge. Knowledge on sow replacement decisions has been acquired for representation in the CHESS-RO knowledge base. The extraction of knowledge from the expert has been done using interviews ("thinking aloud") and protocol analysis using example problems, which are typical and realistic of the sort that the ES will be expected to solve. The interviews using protocol analysis were followed by a refinement phase in which the expert made comments on the transcripts of the interview-sessions.

The current ES is rule-based, which means the knowledge is stored mainly in the form of production rules. Knowledge in a production rule is expressed as "IF premise THEN conclusion", or "IF condition THEN action". The fourth stage, implementation, involved formulating production rules to embody the previously acquired knowledge. From the transcripts of protocol analysis (using the example problems) production rules were generated. This is called "induction", which is a process of reasoning from the specific to the general (Turban, 1988). In fact, this stage also involves programming of knowledge into the computer (ES).

The final stage of knowledge acquisition can be described as testing or validating the ES. Production rules that organize knowledge have been validated. The knowledge engineer has been testing the ES by subjecting it to example problems. As validation is a very important stage in developing computer systems, the validation procedure used for CHESS-RO and the results obtained are described in a separate section.

Each stage of knowledge acquisition involved a circular or iterative procedure (Buchanan *et al.*, 1983; Turban, 1988). This means that the knowledge engineer in cooperation with the expert constantly reformulated, redesigned and refined the ES.

4. THE SOW REPLACEMENT EXPERT SYSTEM

According to the experience of the expert, the sow replacement problem with respect to qualitative sow characteristics can be divided into two major parts: (1) the reasoning process to find deviations in qualitative characteristics, and (2) the economic weighting of the deviations. Both parts are described below. The moment for taking the keep/replace decision is considered to be the moment of weaning.

4.1. Reasoning process to find deviations

Qualitative sow characteristics refer to lameness and leg weakness, mothering characteristics, and udder quality, as was indicated earlier. The expert reasoning process to find deviations in these characteristics is focused on three major elements: (1) clinical or apparent sow deviations, (2) deviations in number of pigs weaned per litter, in relation to (3) deviations in uniformity of the litter. The causal relationships between the sow characteristics and the elements of the expert reasoning process are summarized in Table 1.

Table 1. The relationships between qualitative sow characteristics and the elements of the reasoning process

	Qualitative sow characteristics		
Elements of the reasoning process	Lameness and leg weakness	Mothering characteristics	Udder quality
Clinical/apparent sow deviations	x	x	x
Deviations in number of pigs weaned/litter			
- piglet mortality	x	x	x
- number of pigs crushed by the dam	x		
- number of savaged pigs		x	
- number of stillborn pigs		x	
Deviations in uniformity of the litter			
- number of straggling pigs at weaning	x		x
- number of undersized pigs at birth		x	
- in/decrease in number of straggling pigs	x	x	x
- udder quality			x

Most data and relationships can easily be adjusted to represent a specific herd or a different region of the world.

4.1.1. Clinical sow deviations

If the sow has one or more clinical (apparent) deviations she should be replaced in any case, according to the expert's opinion. This decision should be taken independently of her productive and reproductive performance, which is expressed in her RPO-value determined by the DP-model. Clinical sow deviations can be considered as a binary variable: either the sow has serious clinical problems (for instance serious lameness) and should be replaced, or she does not have clinical deviations and her number of pigs weaned per litter should be evaluated in relation to the uniformity of her litter. The evaluation of clinical sow deviations is presented in Table 2.

Clinical deviations in "lameness and leg weakness" include serious lameness of the sow. Moreover, the number of pigs crushed by the dam during lactation is considered to have a relation with lameness and leg weakness also (Table 2). For this, a distinction has been made between sows with parity number ≤ 2 and sows with parity number ≥ 3. An additional condition for such clinical deviation is that lameness and leg weakness does not apply to more than 15% of the sows present in the herd.

Clinical deviation in mothering characteristics can be detected by evaluating the farrowing performance of the sow and by evaluating savaged newborn piglets (Table 2). The farrowing performance relates to problems associated with farrowing. Difficult farrowing can be described as farrowing which required veterinary assistance (for example Sectio), and was significantly longer than usual. The sow has a clinical deviation if difficult farrowing occurred for the second time in the sow's life. The other point is savaging. This includes all losses of pigs due to behaviour problems of the sow such as hysteria or nervousness. In evaluating savaging, young sows should be distinguished from older sows (Table 2).

A good udder is uniformly smooth. However, a sow may have one or more udder abscesses. Only sows with a (last) litter size above herd average having 1 abscess can be tolerated (Table 2). A second aspect relating to a clinical deviation in udder quality is the number of well located and well developed teats, or alternatively, the number of well functioning milk-producing glands in the sow. A zero parity sow should have at least 14 good teats. Other sows should have more well functioning teats than the expected number of pigs total born in the next parity (Table 2).

Table 2. Evaluation of clinical sow deviations

Conditions for clinical sow deviations		
Lameness and leg weakness		
- parity number ≤ 2	AND	number of pigs crushed by the dam ≥ 2*
- parity number ≥ 3	AND	number of pigs crushed by the dam ≥ 3*
Mothering characteristics		
- parity number 1-9	AND	difficult farrowing for the second time
- parity number ≤ 2	AND	savaging occurred for the second time
- parity number ≥ 3	AND	savaging occurred for the first time
Udder quality		
- PTB_s** ≤ PTB_h***	AND	number of udder abscesses ≥ 1
- PTB_s ≥ PTB_h	AND	number of udder abscesses ≥ 2
- parity number = 0	AND	number of good teats ≤ 13
- parity number 1-9	AND	number of good teats ≤ PTB_h next par****

* per litter; under the additional condition that lameness and leg weakness does not apply to more than 15% of the sows present in the herd (see text)

** PTB_s: number of pigs total born of sow

*** PTB_h: average number of pigs total born of herd in the same parity as PTB_s

**** expected number of pigs total born in the next parity

4.1.2. Deviations in number of pigs weaned per litter

According to the expert, deviations in number of pigs weaned per litter can be found by evaluating the following four (interrelated) elements (see also Table 1): (1) piglet mortality, (2) number of pigs crushed by the dam, (3) number of savaged newborn pigs, and (4) number of stillborn pigs. In considering the first element, piglet mortality rate of the sow is compared with the average piglet mortality rate of the herd in the same parity. Table 3 gives an overview.

Table 3. Evaluation of the piglet mortality rate of the sow before weaning (PMR_s)*

Number of pigs weaned	Conditions for piglet mortality rate	Relative evaluation
≤ 11	$PMR_s \leq 1.0\ PMR_h$**	GOOD
≤ 11	$1.0\ PMR_h < PMR_s < 1.5\ PMR_h$	ATTENTION
≤ 11	$PMR_s \geq 1.5\ PMR_h$	BAD
≥ 12	$PMR_s \leq 1.2\ PMR_h$	GOOD
≥ 12	$1.2\ PMR_h < PMR_s < 1.7\ PMR_h$	ATTENTION
≥ 12	$PMR_s \geq 1.7\ PMR_h$	BAD

* relative evaluation in terms of GOOD, ATTENTION, and BAD

** PMR_h: average piglet mortality rate of the herd in the same parity as the piglet mortality of the sow

As shown in Table 3, two classes of sows should be considered. A sow has either ≤ 11 or ≥ 12 pigs weaned in the last parity. If the sow falls into the first category, and if her piglet mortality rate is less than the parity-specific herd average, she gets the qualification "good". If the mortality rate is between herd average and 1.5 times herd average than her qualification is "attention", while "bad" is the qualification if her mortality rate is more than 1.5 times herd average. The relative evaluation uses the same principle if the sow has ≥ 12 pigs weaned, but with different boundaries: 1.2 and 1.7 times the average parity-specific herd mortality rate (instead of 1.0 and 1.5, respectively; Table 3).

The second and third element relate to number of pigs crushed by the dam, and number of savaged pigs, respectively. Although the piglet mortality as such has been evaluated in the first element (Table 3), the expert could give additional information on the quality of the sow if the piglet mortality during lactation was caused by either the number of pigs crushed or pigs savaged. Therefore, these two elements have been incorporated into the ES. The relative evaluation with respect to these two elements are summarized in Table 4. In both cases, sows with parity number ≤ 2 and parity number ≥ 3 are treated differently. The sow gets the qualification "good" only if there were no pigs crushed by the dam or there were no pigs savaged. The difference between parity number ≤ 2 and ≥ 3 emerges if 2 pigs have been crushed (Table 4).

Table 4. Evaluation of number of pigs crushed by the dam (I), and number of savaged pigs (II)*

Parity number	Number of pigs crushed/savaged			
	0	1	2	≥ 3
I. Pigs crushed				
≤ 2	GOOD	ATTENTION	BAD	BAD
≥ 3	GOOD	ATTENTION	ATTENTION	BAD
II. Pigs savaged				
≤ 2**	GOOD	ATTENTION	ATTENTION	ATTENTION
≤ 2***	GOOD	BAD	BAD	BAD
≥ 3	GOOD	BAD	BAD	BAD

* relative evaluation in terms of GOOD, ATTENTION, and BAD
** savaging just occurred for the first time in the sow's life
*** savaging occurred for the second time in the sow's life

The final element to evaluate, with respect to finding deviations in number of pigs weaned per litter, is the number of stillborn pigs. This is the number of pigs found dead after farrowing, excluding mummified pigs. A low number of pigs weaned may be caused by a high number of stillborn pigs. The latter may be caused by difficult farrowing. Sows with ≤ 5% stillborn pigs (defined as 100 times number of stillborn pigs divided by number of pigs total born) get the qualification "good", and sows with 5% - 20% stillborn pigs "attention". If a sow has ≥ 20% stillborn pigs, a distinction is made between sows with parity number ≤ 4 and ≥ 5. Only if the sow has a parity number ≤ 4, and the high number of stillborn pigs was caused by difficult farrowing, and difficult farrowing occurred for the first time to the sow she obtains the qualification "attention", otherwise she gets the qualification "bad".

4.1.3. Deviations in uniformity of the litter

The third major element concerning the reasoning process of the ES is to find deviations in the uniformity of the litter. According to the expert, finding deviations in this factor consists of evaluating the following four (interrelated) elements (see also Table 1): (1) number of straggling pigs at weaning, (2) number of weak and undersized pigs at birth, (3) increase or decrease in number of straggling pigs during lactation, and (4) udder quality. The first element to consider is number of straggling pigs at weaning. According to the expert, this is the number of pigs in a litter with a lower growth rate than litter average or pigs which develop in an irregular or untidy manner. As a rule of thumb, the expert used a reduction of more than 10% in growth rate. The evaluation of this element depends on a fostering event of the sow. There are three possible fostering events. The first possibility is "foster on". If a sow has farrowed but lost (many of) her pigs for some reason, the farmer may want her being a nurse sow for pigs from one or more other litters. The second possibility is "foster off". If a sow has farrowed a big litter, the farmer may want her contributing pigs to one or more other (small) litters. The third possibility is that there are no pigs fostered on or off. Note that usually the biggest (and strongest) pigs are fostered on or off. Table 5 gives an outline of the evaluation of the number of straggling pigs.

Table 5. Evaluation of number of straggling pigs at weaning without (I) and with fostering of pigs (II)*

Number of straggling pigs at weaning	Relative number of pigs weaned per litter**		
	≤ 90%	90% - 110%	≥ 110%
I. Without fostering			
0	GOOD	GOOD	GOOD
1	BAD	ATTENTION	GOOD
2	BAD	ATTENTION	ATTENTION
3	BAD	BAD	ATTENTION
≥ 4	BAD	BAD	BAD
II. With fostering			
0	ATTENTION	ATTENTION	GOOD
1	BAD	ATTENTION	ATTENTION
2	BAD	BAD	ATTENTION
≥ 3	BAD	BAD	BAD

* relative evaluation in terms of GOOD, ATTENTION, and BAD

** relative to herd average number of pigs weaned in the same parity

This qualification depends on the relative number of pigs weaned by the sow (relative to the herd average number of pigs weaned in the same parity). Table 5 gives an evaluation of the number of straggling pigs at weaning in two situations. Situation I relates to that without a fostering event. The sow is qualified "good" if she weaned no straggling pigs, and "bad" if she weaned ≥ 4 straggling pigs. In the case of 1, 2, or 3 straggling pigs, her qualification depends on her relative litter size at weaning (Table 5). In situation II, which includes pigs fostered on or off, the qualification "good" can only be obtained if the sow has no straggling pigs and her number of pigs weaned is more than 10% above herd average in that parity, else the qualification "attention" or "bad" is obtained (Table 5).

The second element to be considered in finding deviations in the uniformity of the litter is the number of weak and/or undersized pigs at birth. This is the number of pigs with a (very) low birthweight. As a rule of thumb, the expert used a deviation in birthweight of more than 10% below litter average. The qualification of the sow with respect to this elements is "good" if she breeds a litter without weak and/or undersized pigs. The average litter birthweight should be above 1200 grams per piglet. If the latter is not the case, her qualification is "bad" if her relative number of pigs born alive (relative to the herd average number of pigs born alive in the same parity) is more than 20% below herd average, "attention" (if the relative number is 80% - 120% of herd average), or "good" (if the relative number is more than 20% above herd average). If there are weak and undersized pigs at birth, the sow can only be qualified "attention" or "bad". She gets the qualification "attention" if there is only 1 weak or undersized pig and her relative litter size at birth is more than 20% above herd average.

The third element relates to the increase or decrease in the number of straggling pigs during lactation. There are several possibilities for the development of the number of straggling pigs during lactation. The ES evaluates each possible development, in which the value of a sow as a nurse sow is established. If there is a decrease in the number of straggling pigs, the sow obtains the qualification "good", and if there is an increase "bad", and if the number stayed the same "attention".

The final (fourth) element to find deviations in the uniformity of the litter is udder quality. It may be possible that the udder quality of the sow is not optimal. This may include one or more of the following interrelated causes: mastitis, udder abscesses and poor teats. Furthermore, a deviation in udder quality may be either temporary, without a (positive or) negative prognosis on future sow performance, or structural, with a negative prognosis. All combinations of possible deviations in udder quality are evaluated by the ES.

4.2. Economic weighting of deviations

In the previous section, the ES reasoning process has been described with respect to qualitative sow characteristics to identify: (1) clinical sow deviations (2) deviations in number of pigs weaned per litter, in relation to (3) the uniformity of the litter. As mentioned before, if the sow has one or more serious deviations of the first type, she should be replaced in any case. Economic weighting of deviations is, therefore, carried out only for deviations of the second and third type. This is performed as follows. The ES has evaluated the sow on several elements, and translates these global and detailed evaluation results into a sow score on each element, which has a numerical value between -1 and +1. Basically, the qualification "bad" leads to a score of -1, "attention" to a score of 0 (zero), and "good" to a score of +1. The ES then refines these scores on the basis of specific combinations of deviations in the several elements examined. Furthermore, the ES takes into account specific disease factors with respect to the sow or piglets, which may be caused by poor housing facilities, development of injuries and diseases, or poor veterinary treatment. In addition to this, the ES tries to establish the nature of possible deviations, which can vary between temporary, not having a negative prognosis on future sow performance, and structural, having a negative prognosis. So, a sow score of -1 indicates a very bad result, and +1 a very good one. The user of the ES is then asked to quantify maximal economic weights for each of the elements. The unit of the economic weights is "number of pigs weaned per litter". If the sow score per element is multiplied with the maximal economic weight, an actual weight is obtained which is an indication for a deviation in that element. In this way all deviations are expressed in number of pigs weaned per litter. The monetary value of a deviation in an element is calculated by multiplying the actual weight with the economic value per additional pig weaned per litter, which has been determined farm-specifically by the DP-model. Finally, the monetary value of deviations in each element can be added to obtain the total economic value. This total economic value is then added to the original RPO-value of the sow, calculated by the DP-model, to determine the new improved RPO-value. The new RPO-value incorporates an assessment not only for the productive and reproductive performance of the sow (original RPO-value), but also for the qualitative characteristics of the sow (ES added value).

Table 6. Calculation of the economic value of deviations in qualitative characteristics of a sample sow

Elements of the reasoning process	Sow score*	Maximal weight**	Actual weight	Economic value***
Deviations in number of pigs weaned/litter				
- piglet mortality	0.7	0.3	0.21	14.28
- number of pigs crushed by the dam	0.8	0.2	0.16	10.88
- number of savaged pigs	0.5	0.2	0.10	6.80
- number of stillborn pigs	0.5	0.3	0.15	10.20
Deviations in uniformity of the litter				
- number of straggling pigs at weaning	-0.3	0.2	-0.06	-4.08
- number of undersized pigs at birth	0.0	0.1	0.00	0.00
- in/decrease in number of straggling pigs	-0.5	0.4	-0.20	-13.60
- udder quality	-0.2	0.3	-0.06	-4.08
		---+	-----+	------+
TOTAL		2.0	0.30	20.40

* a numerical value between -1.00 and +1.00
** default values for maximal weights expressed as number of pigs weaned per litter (user defined)
*** in Dfl., using an economic value of an additional pig weaned per litter of Dfl. 68

As an illustration, the calculation of the economic value of deviations in the qualitative characteristics of a sample sow is given in Table 6. The sample sow is a sow with average productive and reproductive capacity at the beginning of the fifth parity. The global and detailed evaluation of the sow is translated by the ES in a sow score per element. Major good scores (positive deviations) are obtained in "piglet mortality" and "number of pigs crushed by the dam", and bad scores (negative deviations) in "in/decrease in number of straggling pigs". The sample sow has positive or desirable deviations in the field of "number of pigs weaned per litter", and negative or undesirable ones in the field of "uniformity of the litter". Given the maximal economic weights per element, which are user defined, the actual weights are determined. The total of the maximal weights were determined by the expert on 2.0 pigs weaned per litter, or in other words, the greatest possible effect can be ± 2 pigs weaned per litter. Due to the refinements made by the ES, not all sow scores equal -1 or +1 and the total of actual weights equals 0.30 pigs weaned per litter. The economic value of deviations is calculated by multiplying the actual weights with Dfl. 68 (the economic value of an additional pig weaned per litter equals 68 Dutch guilders in this case). The total economic value of deviations in qualitative characteristics turned out to be Dfl. 20.40. The sample sow has an original RPO-value of Dfl. 73.64 (outcome DP-model). Her new improved RPO-value can be calculated by adding the total economic value of Dfl. 20.40 to the original RPO-value (Dfl. 73.64) as Dfl. 94.04.

5. VALIDATION OF THE SYSTEM

5.1. Materials and methods

The final step in developing CHESS-RO was validation. Validation is an important stage in developing computerized systems, to be described as comparing the computer system with the real world (Gilchrist, 1984). However, measurement of the validity of any system is difficult. Due to its nature, it is hard to define a "golden standard" against which the ES's performance can be compared. Therefore, the system has been validated by comparing its results with results of two experts including the domain expert used before for knowledge acquisition. Thirty different sow scenarios were constructed. Validation was then divided into two major parts: (1) both the ES and the experts assessed the qualitative characteristics of the 30 sows, and (2) the 30 sows were ranked on a scale of 1 (extremely bad) to 30 (extremely good) both by CHESS-RO and the experts. The first part refers to the qualitative sow characteristics only and not to the productive and reproductive performance of the sow. Consequently, for the first part the ES was used only. To facilitate comparison, the assessments were divided into six classes. Sows with clinical deviations were placed into class "replace". Furthermore, deviations in qualitative sow characteristics with an economic impact of less than Dfl. -40 were placed into class "very bad", with an economic impact between Dfl. -40 and -15 into class "bad", between Dfl. -15 and +15 into class "average", between Dfl. +15 and +40 into class "good", and finally deviations with an economic impact greater than Dfl. +40 into class "very good". The percent test agreement between CHESS and the experts can be defined as percent assessments classified into the same classes (replace, very bad, bad, average, good, very good).

In the second part, the ranking was based on the entire sow performance, including qualitative, productive and reproductive characteristics. So, both the DSS (i.e. DP-model) and the ES were used. These 30 scenarios were presented independently to the experts as a blind test to obtain their assessments and rankings. The rankings are tested using the Spearman's rank correlation coefficient. In general, this coefficient is a measure of correlation between 2 rankings, or in other words, a statistical measure of the degree of association between n pairs of observations of 2 variables

(Gibbons, 1971; Yamane, 1973). The objective is to test the following null hypothesis: the observations are independent, which means that the rank correlation coefficient is zero.

5.2. Results

A summary of the validation results of the first part is provided in Table 7. Percent test agreement between CHESS-RO and expert 1 was 67% ((5+5+3+1+4+2)/30; see Table 7A). Only the classification of one sow was significant different between CHESS-RO and expert 1: "replace" versus "good". Percent test agreement between CHESS-RO and expert 2 turned out to be 67% also ((5+5+2+1+4+3)/30; see Table 7B). Considerable different classification between CHESS-RO and expert 2 were not found.

The validation results of the second part are as follows. Spearman's rank correlation coefficient r_S has been calculated as 0.685 (between CHESS-RO and expert 1), and 0.815 (between CHESS-RO and expert 2). As $n > 20$, the distribution of r_S approaches a normal curve with a zero mean and a variance equal to $(n-1)^{-1}$ or 0.0345 (Yamane, 1973). The Spearman's test variable z, defined as r_S divided by the square root of the variance (being the standard error), turned out to be 3.686 (between CHESS-RO and expert 1), and 4.388 (between CHESS-RO and expert 2), respectively. This means that r_S is 3.686 and 4.388 standard deviations away from 0 in the sampling distribution, and hence there is a significant difference between 0 and both rank correlation coefficients r_S ($p < 0.001$). The null hypothesis is rejected and the alternative hypothesis that the rankings made by the experts and CHESS are not independent is accepted. So, the outcome of the second part of the validation process is that the system has not been proved invalid.

So far, it has been assumed that the two domain experts used in validation of CHESS-RO have the same level of expertise. The validation results can also be used to test this assumption. In Table 7C the two experts are compared with respect to the qualitative sow characteristics. Percent test agreement between the two experts was slightly lower than the test agreement between CHESS-RO and each single expert: 60% ((4+4+2+2+4+2)/30). Note that the classification of one sow was significant different between the experts (see also the comparison of CHESS-RO and expert 1). Spearman's rank correlation coefficient r_S equaled 0.704, and test variable z was 3.792. So, the rankings made by both experts are not independent ($p < 0.001$), and they are considered to have the same level of expertise.

Table 7. Comparison of the analysis results of the ES of CHESS-RO and the two domain experts

A. ES versus expert 1

Classification of ES	Classification of expert 1						
	replace	very bad	bad	average	good	very good	TOTAL
replace	5*	0	0	0	1	0	6
very bad	1	5	0	0	0	0	6
bad	1	1	3	0	0	0	5
average	0	0	0	1	0	0	1
good	0	0	0	1	4	0	5
very good	0	0	0	2	3	2	7
TOTAL	7	6	3	4	8	2	30

B. ES versus expert 2

Classification of ES	Classification of expert 2						
	replace	very bad	bad	average	good	very good	TOTAL
replace	5*	1	0	0	0	0	6
very bad	1	5	0	0	0	0	6
bad	0	2	2	1	0	0	5
average	0	0	0	1	0	0	1
good	0	0	0	1	4	0	5
very good	0	0	0	2	2	3	7
TOTAL	6	8	2	5	6	3	30

C. Expert 1 versus expert 2

Classification of expert 1	Classification of expert 2						
	replace	very bad	bad	average	good	very good	TOTAL
replace	4*	3	0	0	0	0	7
very bad	1	4	0	1	0	0	6
bad	0	1	2	0	0	0	3
average	0	0	0	2	2	0	4
good	1	0	0	2	4	1	8
very good	0	0	0	0	0	2	2
TOTAL	6	8	2	5	6	3	30

* numbers refer to the total number of sows classified in each category

6. DISCUSSION AND OUTLOOK

Current systems to support replacement decisions in livestock mainly base their results on productive and reproductive characteristics of animals. In dairy cattle such characteristics may include: lactation number, stage of lactation, milk production level, time of conception, and month of calving (see for instance Van Arendonk, 1985; Kristensen, 1987). In swine breeding these characteristics mostly include: parity number, litter size, and time of conception (see for instance Dijkhuizen *et al.*, 1986; Huirne *et al.*, 1988, 1990[a], 1990[b]). Extending such decision support systems (DSS) with expert systems (ES) can make them more valuable and appropriate for replacement decision-making, as shown in this chapter with respect to sows (Figure 1). The objective of the integration is to combine the strong points of both the DSS and ES (Huirne, 1990). In this way the integration has the advantage of yielding synergetic results. The DSS is well suited to carrying out the calculation-algorithms (DP-model) needed for obtaining the optimal replacement policy based on productive and reproductive sow characteristics. On the other hand, ES are very well suited to incorporating expert knowledge (rules of thumb, and heuristics) on qualitative sow characteristics into the optimization process. The output of the DSS is used as input to the ES.

As indicated in this chapter, the original RPO-values of sows can potentially differ considerably from the corrected values, which are obtained by taking into account qualitative sow characteristics. This also results in a new ranking of the sows present in the herd. However, changes in sign of the RPO-value are generally found only for a limited number of sows. For these sows, the "keep" or "replace" decision will probably change.

In this study, expert knowledge with respect to qualitative aspects of the sow replacement problem has been captured and incorporated into an ES successfully. However, some difficulties were involved in acquiring knowledge for the ES. The most troublesome was the representation mismatch. This is the difference between the way the human expert normally states knowledge and the way the knowledge must be represented in the knowledge base of the ES (Turban, 1988).

It is hard to define a "golden standard" against which the performance of an ES can be compared. Hardly any literature can be found to check the knowledge incorporated into the ES. Therefore, the system has been validated against answers of two domain experts. A problem of this method has been that the experts disagreed on certain details. Furthermore it is also possible that both ES and the experts are wrong. The latter may occur even in the expert's area of expertise. Further validation is necessary in a (large) field test using more sows of different farms to gain insight into the behaviour of the system on a larger scale before it can be used in practice.

ES which operate outside a controlled environment are subject to the dynamics of their environment. The sow replacement ES in CHESS-RO is no exception. Expertise, as represented by rules of thumb and heuristics, for instance, vary over time. Although the ES was structured to minimize its sensitivity to the dynamics, it is obvious that it requires maintenance during its life cycle so it will continue to be an acceptable representation of the expert. Furthermore, as use of ES will increase in future, it is essential to further develop and use scientifically sound methods for validating their performance.

In practice, the potential users of CHESS-RO may be found in the following fields: (1) research, (2) extension, (3) teaching and education, and (4) individual decision-making (swine breeding farmers). The system has especially great potential applicability to (veterinary) extension workers and swine breeding farmers. If they supply their own expectation or estimates of input parameters, the system will generate optimal replacement decisions as it applies to their particular cases. For instance, they may replace the default weightings of the subjective characteristics by their own weightings. Furthermore, it is intended to use the system as a teaching tool at the Veterinary Faculty of University of Utrecht. The system enables the students to interact with knowledge in a way that stimulates their diagnostic abilities.

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GENERAL DISCUSSION

1. INTRODUCTION

The present study is directed towards computerized management support for swine breeding farms, focused on sow productivity and profitability. It is composed of three parts. First, a basic description and definition of farm management, management information systems (MIS), decision support systems (DSS) and expert systems (ES) are given, to provide a solid basis for the second and third part of the study (Chapter 1). In the second part, a method for computerized individual farm analysis has been developed (Chapter 2) and validated (Chapter 3). The result of this part is the identification and weighting of strong and weak elements in the farm's management. In the third part of the study, attention has been given to one of such elements: the sow replacement policy. A stochastic dynamic programming model (DP-model) has been developed and validated with respect to mathematical (Chapter 4) and zootechnical-economic (Chapter 5) aspects. Finally, results of the DP-model are refined by an ES with respect to qualitative sow characteristics relevant to the replacement problem (Chapter 6).

In each of these chapters, objectives, methods, limitations and results have been described and discussed. This final chapter, therefore, contains a general discussion, which is directed towards the following major areas: integrated decision support (section 2), and value of management information systems (section 3). Finally, the main conclusions of the study are presented (section 4).

2. INTEGRATED DECISION SUPPORT

2.1. Scope and definition

Management has been described as the decision-making process in which limited resources are allocated to a number of production alternatives (Chapter 1). Due to increasing herd size, narrowing income margins and a rapidly changing environment, modern swine breeding imposes increasing demands on the farmer's management skills. The need for accurate and consistent information for management support, therefore, is evolving. Recent advances in computer technology help make it possible to provide such information. Computerized management support generally results in increased effectiveness and efficiency of decision making (Chapter 1). Hogarth (1987) recognized, however, limitations in the human information-processing capacity and the way in which they make judgemental errors because of the limited capacity of the human mind. So, decision support should be focused on the limited number of farm-specific areas in which satisfactory results will ensure successful farm performance, named "critical success factors" (Rockart, 1979). Information supply should be derived from and be dependent on these critical success factors, as much as possible.

On the other hand, decision support is very complex (Chapter 1). There are interactions between single aspects of farm management which determine whether or not aspect-specific recommendations are optimal in the wider farm management context. There may be objectives which can only be given appropriate weights when considered in relation to other management aspects. Moreover, a swine breeding farm can be considered as only one of the components in a production chain operating between forward and backward connected chain components under uncertain conditions. Examples of forward connected chain components are pig fattening farms and slaughter houses. Feed companies and farms producing replacement gilts are examples of backward connected components. In anticipation of given government regulations, new emerging technologies and changing institutions, it is often insufficient for farm managers to optimize management decisions at the farm level only, but it is increasingly necessary to take more components of the whole production chain into consideration. Most MIS however, including DSS and ES, are focused on a single aspect and their output need interpretation and widening to the circumstances of the particular application. Mostly the results cannot be used directly. So, the need for an integrated approach is emerging. The different management aspects, therefore, should be combined into a whole. Generally, the following aspects may be integrated into a MIS: (1) phases of decision making (Chapter 1): intelligence, design and choice, (2) areas of farm management (Chapter 1): production, marketing and finance, (3) functions of farm management (Chapter 1): planning, implementation and control, (4) different mathematical methods, techniques and types of computer systems used, such as optimization (dynamic programming, linear programming), simulation (Monte Carlo method, models of differential equations), DSS and ES, and (5) other MIS. The latter (fifth) possibility includes other MIS of the same farm, MIS of other farms, and MIS of forward and backward components (buyers and suppliers, respectively) of the production chain.

Basically, all integrations are likely to produce synergetic benefits. They are however far more complex to realize than the above list suggests. Consider the following example on the integration of the decision-making phases. In general, the intelligence activity precedes design, and design precedes choice (Chapter 1). Each phase in making a particular decision is in itself a complex decision-making process (Simon, 1977). The design phase, for example, may call for new intelligence activities. Problems at any given level generate subproblems that, in turn, have their own intelligence, design and choice phases, and so on. Similar problems exists for other types of integration. So, designing integrated systems for decision support is a very complicated task. The challenge is to design MIS that take advantage of the power of integration yet are well adapted to both the strengths and weaknesses of humans as problem solvers. Moreover, such (parts of) MIS should fit into a general framework for information systems. In the Netherlands, such a framework is called an information model (Chapter 1).

2.2. The management information system CHESS

As mentioned previously, the management information system CHESS, developed in this study, consists of two basic parts: individual farm analysis and sow replacement optimization. A major issue in developing both parts has been to concentrate the information supply on the critical success factors of swine breeding farms. Consider individual farm analysis for instance. Evaluation of individual farm performance could be reduced to the following six major areas for special attention (Chapter 2): nutrition, health care, reproduction, housing, input and output of animals, and prices. These major areas are divided further into twelve subareas. Satisfactory results in these (sub-)areas generally result in successful farm performance (Chapter 2 and 3). Another example relates to sow replacement optimization. A major activity in this field is the calculation of the future profitability (RPO value) of individual sows present in the herd which can be used as a management guide in culling decisions. Several sow characteristics could be combined into this RPO value, such as productive, reproductive and more qualitative characteristics (Chapter 4, 5 and 6).

CHESS includes several types of integration. Most attention was given to the integration of DSS and ES. This has been realized in both basic parts of CHESS. Both quantitative and qualitative information is needed to solve many problems in these areas. Such problems, therefore, can not be solved with either DSS or ES alone. The object of such an integration is to combine the strong points of both DSS and ES (Chapter 1). In the case of individual farm analysis, this means that the ES is used for evaluating the herd performance, taking into consideration, among other things, refinements of assumptions made by the DSS (such as correction of normal distributions assumed for some variables) and indirect relationships between variables (Chapter 2). In the case of sow replacement optimization, an ES has been developed and integrated for two reasons. First, due to the so-called curse of dimensionality it is not possible to extend the size of the DP-model by taking additional variables into account (Chapter 4). Second, due to the algorithmic nature of the DSS (i.e. DP-model), it is very difficult to include the more qualitative sow characteristics relevant to the replacement problem (Chapter 6). Another integration in CHESS, which has been shown to be successful, is the top-down concept developed within the control management function. It consists of two parts. The first part is composed of individual farm analysis in which technical and economic records of individual farms are analyzed globally to find strong and weak elements in the farmer's management (Chapter 2 and 3). In the second part, a more detailed analysis in depth is carried out with respect to relevant problems (weak elements) detected in the first part. The sow replacement problem is an example (Chapter 4, 5 and 6). Furthermore, the sow replacement optimization part of CHESS can be considered to be an integration of the planning and the control function. Problems in the replacement policy are detected by the system and the optimal course of action is provided.

2.3. Further research

Further research is needed to integrate more aspects into CHESS. Especially other subfields for detailed analysis of the production management area should be considered. The fields with the greatest potential are nutrition and health care. Furthermore, research to extend CHESS with discrete simulation facilities would be desirable. Consider, for example, the sow replacement problem. The current version of CHESS determines the economically optimal replacement policy (Chapter 4, 5 and 6). Simulation offers the opportunity to evaluate and compare the consequences of the optimal and several suboptimal replacement policies under uncertain farm and animal conditions. The farmer's decision-making behaviour under uncertainty, which has not been considered in the current study, can be divided into three classes (Dannenbring and Starr, 1981): risk-seeking, riskneutral and risk-averse. The suboptimal policies may include simplifications that are easier to implement in the field. The DP-model of CHESS can be used as a basis for the simulation model at the animal level, and as a tool of reference. More research is also needed to investigate the need and possibility of integrating CHESS with MIS of forward and backward connected firms in the production chain. Examples of such firms include swine nucleus farms that sell genetic materials, feed companies that sell feedstuffs, and pig fattening farms that purchase feeder pigs. Such an integration, therefore, would be especially focused on the sow replacement optimization part of CHESS. External conditions under which the replacement optimization takes place should be provided. The conditions can then be used in the optimization to create a value added chain.

Possibilities for application of the technique of individual farm analysis to other farm enterprises are also worth considering in future research. Particular attention should be focused on pig fattening, dairy and poultry enterprises. Much of the data needed for analyzing these enterprises is available today, and can be used in a system for individual farm analysis to regularly detect deviations between performance and standards at an early stage so that further analysis and corrective actions can be taken rapidly. The latter may require the availability of detailed systems for planning and control.

Since there are few fundamental differences between culling decisions for sows, dairy cows, and flocks of laying hens, further research should also be directed towards application of the sow replacement technique to these species. Currently, support for replacement decisions of dairy cows and flocks of laying hens is only possible with research models available on the mainframe computer (see for instance: Van Arendonk, 1985; Van Horne *et al.*, 1990). To be frequently used and widely accepted, however, such systems should be user-friendly and suitable for use in the field and, therefore, available on the personal computer (PC). Further investigation may also be focused on application of the integrated DSS-ES approach to fattening animals (calves, poultry and hogs). In fact, these decisions can also be described as multistage decision problems, which involve a sequence of decisions extending over a given planning horizon, and are therefore, suitable to be solved by dynamic programming. Qualitative knowledge can be used in the optimization by incorporating it into an ES, which is coupled with the dynamic programming model.

Finally, more research is needed to gain insight into possibilities of the practical implementation of CHESS. In general, different strategies are available for the MIS implementation, of which the "life cycle" approach is the most common (Davis and Olson, 1985). It consist of three major stages: (1) definition, defining information requirements, (2) development, translating the requirements into a physical MIS, and (3) installation and operation, testing and putting the MIS into operation. Activities of the third stage can be used for implementing CHESS. This stage includes the following elements: final system test, user training, day-to-day operation, modification, maintenance, and user experiences. The life cycle approach is described in detail by Davis and Olson (1985). The actual implementation strategy also depends on the different uses that might be made of CHESS. Four potential uses of CHESS can be distinguished: research, extension, on-farm decision support (individual decision making), and teaching. Because each type of user has unique analytical skills, computer experience, knowledge base, and other characteristics, users' needs must be carefully considered when implementing CHESS. An important additional benefit of using CHESS is that the users learn from CHESS which, after a time, they may no longer need to consult. In other words, users become conscious of the major (aspects of) decision problems.

3. VALUE OF MANAGEMENT INFORMATION SYSTEMS

3.1. Scope and definition

Insight into the value of information and MIS is important both as a guide for MIS design efforts and as a means for advising farmers whether or not to start with computer-based MIS. The complexity of the valuation problem increases when the focus of attention moves from particular kinds of information to an entire MIS (Kleijnen, 1980). At this level, recognition of important decision problems at an early stage and avoidance of responses to irrelevant "problems" may be as important as the benefits of improved decisions. In addition, increased timeliness and reductions in labour requirements in making and implementing decisions, existence of less tangible benefits such as increased confidence in decisions and more effective communication within and outside the farm are also important determinants of the overall value of a MIS (King *et al.*, 1990).

The value of goods is generally determined by the supply-and-demand market mechanism. Unfortunately, the market mechanism for information and MIS is not yet well-developed. So, it is inadequate for determining the exact value of information and MIS (Kleijnen, 1980). Therefore, an alternative two-stage approach is suggested. In the first stage, the traditional cost-benefit analysis is considered a useful method for justification of MIS projects. Traditional cost-benefit analysis has two major components (Anthony and Dearden, 1980): (1) costs analysis, and (2) benefit estimation. These components are compared mostly in monetary terms, based upon a capital budgeting criterion, such as net present value, internal rate of return, or payback period (Pieptea and Anderson, 1987). The value of a MIS is the value of the change in decision behaviour caused by the MIS, less the costs of obtaining the information (Davis and Olson, 1985). Unfortunately, there is no important decision situation in which all the relevant factors can be reduced to numbers, nevertheless, reducing some of the important factors to quantitative terms is often better than not doing so. The resulting analysis narrows the area within which management judgement is required, even though it does not eliminate the need for judgement. An example may help to explain the latter statement. Consider the sow replacement problem (Chapter 4, 5 and 6). Qualitative sow characteristics, such as lameness and leg weakness, mothering characteristics, and udder quality, have been quantified by the ES, and are used to refine the results of the DP-model (i.e. RPO values of individual sows). So, the ES reduces the need for the farmer's judgement with respect to these qualitative characteristics of the sow replacement problem. Description of theoretical models for analyzing and evaluating information for farmer decision making and their limits can be found elsewhere (for example, see Anderson *et al.*, 1980; Byerlee and Anderson, 1982).

The second stage in the approach includes an extension of the cost-benefit analysis for determining the value of a MIS. According to Keen (1986) and Kleijnen (1980) traditional cost-benefit analysis alone does not seem to contribute much to the analysis of the value of computerized MIS. As mentioned before, the benefits are often qualitative, which means that there are both tangible and intangible benefits. Intangible benefits can be defined as benefits that cannot be established because, either there are no appropriate variables to measure them, or the precision in measuring the variables is inadequate (Toraskar and Joglekar, 1990). Furthermore, it is extremely difficult to place a monetary value on intangible benefits. For these reasons, they are generally overlooked by traditional cost-benefit analysis, although many MIS are primarily justified by such benefits (Pieptea and Anderson, 1987). In addition, most MIS evolve. There is no "final" system; an initial version is built and new facilities are added in response to the users' experience and learning. Because of this, the development costs of a MIS are not easy to identify. The decision to build or buy a MIS should be based on value less costs. The system should be considered to represent an investment for future effectiveness (Keen, 1986).

An important intangible benefit provided by MIS (in particular by DSS) is their ability to perform sensitivity analysis. In a "what-if..." approach, the system is rerun for successive scenarios (Chapter 3, 4 and 5). This may include identifying the value of additional information about decision-sensitive variables. The ability to test alternative assumptions regarding the analysis carried out may be a reason for the system to be highly valued by most decision makers.

In general, both the costs and benefits of MIS are influenced by the degree of integration included into the system (see previous section). Especially with respect to the fifth possibility for integration, namely the integration with other MIS, successful integration may reduce costs when less user interaction is needed because of automated data capture, entry and transfer. Prevention of data handling mistakes will improve accuracy and precision of the MIS results and reduce the risk of incorrect decisions. Benefits may also increase as the degree of integration increases. The most important aspects and perspectives of the decision problem can be examined by using, for instance, integrated optimization-simulation models, integrated planning-control models, or integrated production-finance models.

3.2. Further research

More research is needed to determine the value of (parts of) CHESS. Starting with the first stage in the above-described approach, two methods can be followed: a normative and a positive method. The normative method is focused on the examination of the economic effects of CHESS, using existing or evolving discrete simulation models. Simulation offers the opportunity to take into account risk and uncertainty, under which decisions are, in fact, taken in practice. Risk is the situation where all possible outcomes are known for a given management decision and sufficient information is available to calculate statistical probabilities associated with each possible outcome. Uncertainty is the situation where all possible outcomes or probabilities are not known (Chapter 1). A sensitivity analysis has already been carried out to gain insight into the behaviour of CHESS under different conditions (Chapter 3, 4 and 5), but more sensitivity analyses are needed to determine the additional monetary benefits of the system. The second method is the positive method. Technical and economic data of farms actually using CHESS should be evaluated in this method. Two possibilities should be considered: (1) comparison of the performance of a group of farms that uses CHESS (treatment group) to that of a control group that does not use it, and (2) a "cross-section" analysis of farms using CHESS. The latter relates to collecting data from these farms to be used to estimate a production function that describes how CHESS-expenditures substitute for and/or complement other inputs (King *et al.*, 1990). The second stage of the approach should be concentrated on the assessment of intangible benefits of CHESS. Field experiments with CHESS are proposed to gain insight into these benefits.

It should be realized that the value of a MIS also depends on the underlying assumptions built into the system. An example may explain this statement. Consider the sow replacement optimization part of CHESS. Given the marginal probabilities of involuntary disposal, the optimal replacement decisions resulted in a present value of expected annual net returns per sow of Dfl. 852 (Chapter 5). If all sows are kept until they have to be replaced involuntarily, the present value of expected annual net returns per sow decreases by only Dfl. 10 (Chapter 5). The key factor in this field is the repeatability of litter size among sows, which is commonly accepted to be low. Additional calculations with repeatability factors doubled show that the expected annual net returns per sow increase from Dfl. 852 to Dfl. 868. Due to these higher repeatability factors, the difference in expected annual net returns per sow between the situation with and without voluntary disposal increases from Dfl. 10 to Dfl. 27. The same caveat applies to other relations, such as repeatability of reproduction failure. So, the biological foundation of the models used in a MIS are of paramount importance. With regard to CHESS, further investigation is particularly needed to determine whether the above-mentioned repeatability factors are as low as commonly accepted.

More work is also needed to investigate the slow adoption rate for computer-based farm MIS. Research should be focused on the farmers' actual information and MIS needs, and on the way to meet the needs effectively. Davis and Olson (1985) provide the following complementary methods for assessing these needs: (1) direct questioning, (2) derivation from existing systems, (3) synthesis from characteristics of the processes being managed, and (4) discovery from experimentation with an evolving system (prototyping). Synthesizing methods are particularly effective because they focus attention on objects, activities and processes that are familiar to farm managers. Furthermore, synthesizing methods may include several types of statistical and economic analyses using data from the processes involved. Such analyses can also quantify the significance of remaining gaps in knowledge or identify variables for which more information will be valuable.

4. MAIN CONCLUSIONS

The main conclusions of the present study are:

- Recent advances in computer technology enable the support of realistic farm management decisions on the personal computer. As applications on the personal computer are suitable for use in the field, the relevance of on-farm decision support increases (Chapters 1-6).
- Integrated decision support and expert systems make it possible to formulate and solve major problems in the fields of individual farm analysis (Chapter 3) and sow replacement optimization (Chapter 6).
- In finding strengths and weaknesses in the management of individual - swine breeding - farms, three types of analysis are to be recommended: (1) trend analysis, comparing the actual herd performance against predictions based on the herd's historical data, (2) comparative analysis, comparing the actual herd performance with the average performance of similar herds, and (3) comparative trend analysis, comparing the historical development of the herd performance with the average development of similar herds (Chapter 2 and 3).
- In carrying out computerized farm analysis it is recommended to use the top-down approach: first providing a global economic overview of the farm and then making a specific choice for detailed analysis of relevant (sub)problems, such as the sow replacement problem (Chapter 2).
- In supporting sow replacement decisions, it is advisable to calculate the future profitability for individual sows based on both the quantitative productive and reproductive sow characteristics and the more qualitative characteristics, including lameness and leg weakness, mothering characteristics and udder quality (Chapter 4, 5 and 6).
- Validation of expert systems is difficult but possible (Chapter 3 and 6).

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SUMMARY

1. INTRODUCTION

The investigations described in this thesis have been directed towards computerized management support for swine breeding farms, focused on sow productivity and profitability. The study is composed of three basic parts: (1) basic description and definition of farm management and management information systems (MIS), (2) individual farm analysis, and (3) sow replacement optimization. As part of the study, a MIS on the personal computer named CHESS (Computerized Herd Evaluation System for Sows) has been developed. CHESS is primarily intended to support farm managers and other livestock specialists in analyzing the economic situation of individual sow-herds. Data, knowledge and expertise from many sources are required to find solutions to problems in these fields. As most problems cannot be solved with mathematical problem-solving techniques only (such as dynamic programming), CHESS consists of both decision support systems (DSS) and expert systems (ES). This study should also give insight into the underlying question of whether the combination of DSS and ES is of any advantage in formulating and solving major problems in the above-mentioned fields.

Basic concepts of computerized support for farm management decisions are described in Chapter 1. Good management is essential for efficient and effective operation of any farm, but the concept of management is nebulous and difficult to define. Therefore, scope and definition of farm management is discussed first, by paying attention to the three major management functions: planning, implementation and control. Then, impact of recent advances in computer technology on farm management and concept of MIS are described. Two potential applications of MIS are presented: DSS and ES. A DSS can be described as an information system that supports the process of making decisions. A DSS allows the decision maker to retrieve data, generate and test alternative solutions during the process of problem solving, and incorporates a variety of models. An ES can be defined as a computer program using expert knowledge to attain high levels of performance in a narrow problem area, and thus can be considered as a modelling of the human reasoning process, making the same decisions as its human counterpart. The current challenge in building MIS is to incorporate DSS and ES to create an effective tool for farm managers. This should take place within a general framework for integrated information systems. In the Netherlands, such a framework is called an information model.

2. INDIVIDUAL FARM ANALYSIS

The second basic part of this study is concentrated on individual farm analysis, which can briefly be described as the global analysis of technical and economic farm records in order to find strong and weak elements in management. In Chapter 2, a systematic and objective methodology for individual farm analysis has been developed and discussed. The methodology includes three types of analysis: (1) trend analysis, comparing the actual herd performance against predictions based on the herd's historical data, (2) comparative analysis, comparing the actual herd performance with the average performance of similar herds, and (3) comparative trend analysis, comparing the historical development of the herd performance with the average development of similar herds. In each type of individual farm analysis the following four stages are being considered: tracing deviations, weighting deviations, further analysis of deviations, and evaluation of individual farm performance.

This methodology for analyzing the economic and technical records of individual swine breeding herds has been incorporated into CHESS. The individual farm analysis part of CHESS consists of both one DSS and three ES, designed in a modular manner. The DSS identifies and assesses the importance of relevant deviations between performance and standards. Its output is used in the ES that try to find strengths and weaknesses by combining and evaluating the previously identified deviations. As a supporting technique for the farm manager, the system can also be used for determining the maximum amount that could be spent in exploiting or improving farm performance.

In Chapter 3, the validation procedure used for the individual farm analysis part of CHESS is outlined. Validation can be described as comparing CHESS with the observed world. It is generally considered as an important and difficult stage in developing computerized systems. This is especially the case for ES where symbolic problem-solving techniques and heuristics are used to draw conclusions. A methodology for validating this part of CHESS has been developed and described. Both the DSS and ES components of CHESS have been validated using, among others, a sensitivity analysis. Furthermore, a field test of the integrated system as a whole has been carried out. The field test resulted in a test agreement between CHESS and experts of about 60%. The percent mis-classification error turned out to be 4% only. The knowledge of the experts has thus successfully been incorporated into CHESS. So, CHESS shows to be a promising tool in performing - theoretically sounded but widely accessible - individual farm analyses.

3. SOW REPLACEMENT OPTIMIZATION

In the third basic part of the study, attention is focused on one of the strong or weak elements resulting from the individual farm analysis: the sow replacement policy. In Chapter 4, a (stochastic) dynamic programming model (DP-model) on the PC, which has been added to CHESS, is introduced to determine the economic optimal replacement policy in swine breeding herds. This optimal policy maximizes the present value of expected annual net returns from sows present in the herd and from subsequent replacement gilts over a given planning horizon. Sows are described in terms of parity number, production level in previous parity, production level in the next to previous parity, and number of unsuccessful breedings in the current parity. As the DP-model includes a large number of state and decision variables, a major issue in this chapter is how to cope with the resulting curse of dimensionality. This results in an alternative DP-model structure. Furthermore, a sensitivity analysis has been carried out to achieve insight into possibilities for further reduction of the model size. In this process, the quality of the results obtained are weighed against the amount of computation time needed to carry out the calculations on the PC. These two variables are especially sensitive to reductions in the maximum number of parities considered. In the basic situation, 7 minutes and 18 seconds of central processor time are needed for performing the optimization on a PC with an 80286 micro-processor and an 80287 math-processor.

The zootechnical-economic aspects of the DP-model are described in Chapter 5. Besides determining the economic optimal replacement policy, the model calculates the total extra profit to be expected from attempting to retain an individual sow until her optimal lifespan and not replacing her immediately. This total extra profit, called Retention Pay-Off (RPO), is an economic index which makes it possible to rank sows within a herd on future profitability and, therefore, can be used as a management guide in culling decisions. Given the probabilities of involuntary replacement, the optimal replacement policy results in an average herd life of 5.5 parities. The corresponding present value of expected annual net returns per sow equals Dfl. 852. The optimal economic life of average producing sows emerges as 9 parities. The optimal policy is most sensitive to the difference between the cost of a replacement gilt and the slaughter value of culled sows. Moreover, conception rates have a considerable effect on net returns, replacement rate, and average herd life.

Usually, replacement decisions are not based on productive and reproductive sow performance only, but also on more qualitative sow characteristics such as lameness and leg weakness, mothering characteristics and udder quality (Chapter 6). Therefore, CHESS has been extended with an ES for the economic optimization of sow replacement decisions focused on such qualitative characteristics. The ES is integrated with the DP-model by using its output as input. The reasoning process of the ES is focused on three major elements: (1) clinical sow deviations, (2) deviations in number of pigs weaned per litter, in relation to (3) deviations in uniformity of the litter. Deviations of the first type always result in the advice to replace the sow by a replacement gilt. After deviations of the second and/or third type have been found, they are weighted economically by the ES. The RPO values determined by the DP-model are then adjusted by the ES based on these economic weights. The method of acquiring the knowledge (rules of thumb, heuristics) for the ES involved direct interviews with a domain expert. Real and example problems have been used in these interviews. Formal validation results indicate a high correspondence between the system's ranking of 30 blind test scenarios with the rankings provided by both the domain expert and a second expert. The adjusted RPO values turned out to be more complete management guides in culling decisions.

4. MAIN CONCLUSIONS

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- Recent advances in computer technology enable the support of realistic farm management decisions on the personal computer. As applications on the personal computer are suitable for use in the field, the relevance of on-farm decision support increases.
- Integrated decision support and expert systems make it possible to formulate and solve major problems in the fields of individual farm analysis and sow replacement optimization.

- In finding strengths and weaknesses in the management of individual - swine breeding - farms, three types of analysis are to be recommended: (1) trend analysis, comparing the actual herd performance against predictions based on the herd's historical data, (2) comparative analysis, comparing the actual herd performance with the average performance of similar herds, and (3) comparative trend analysis, comparing the historical development of the herd performance with the average development of similar herds.
- In carrying out computerized farm analysis it is recommended to use the top-down approach: first providing a global economic overview of the farm and then making a specific choice for detailed analysis of relevant (sub)problems, such as the sow replacement problem.
- In supporting sow replacement decisions, it is advisable to calculate the future profitability for individual sows based on both the quantitative productive and reproductive sow characteristics and the more qualitative characteristics, including lameness and leg weakness, mothering characteristics and udder quality.
- Validation of expert systems is difficult but possible.

SAMENVATTING

1. INLEIDING

Het in dit proefschrift beschreven onderzoek heeft betrekking op de gecomputeriseerde managementondersteuning van zeugenbedrijven en is in het bijzonder gericht op de produktiviteit en rendabiliteit van de zeugen. De studie bestaat uit drie onderdelen: (1) beschrijving en definitie van management en management-informatiesystemen (MIS), (2) individuele bedrijfsanalyse, en (3) optimalisatie van het vervangingsbeleid bij zeugen. Als onderdeel van de studie is een MIS voor de personal computer ontwikkeld genaamd CHESS, hetgeen de Engelstalige afkorting is van Computerized Herd Evaluation System for Sows (gecomputeriseerd evaluatie-systeem voor zeugenbedrijven). CHESS is in eerste instantie bedoeld ter ondersteuning van zeugenhouders en begeleiders bij de economische analyse van de individuele bedrijfsresultaten. Gegevens, kennis en expertise uit verschillende bronnen zijn nodig voor het vinden van oplossingen van problemen op de genoemde terreinen. Aangezien de meeste van dergelijke problemen niet kunnen worden opgelost met alleen wiskundige probleemoplossende technieken (zoals bijvoorbeeld dynamische programmering), bestaat CHESS uit zowel decision-support-systemen (DSS; beslissingsondersteunende systemen) als uit expertsystemen (ES). Deze studie moet tevens inzicht geven in de onderliggende vraag of de combinatie van DSS en ES zinvol gebruikt kan worden voor het oplossen van belangrijke problemen op de genoemde terreinen.

De basisconcepten voor de gecomputeriseerde ondersteuning van het nemen van managementbeslissingen op landbouwbedrijven worden beschreven in hoofdstuk 1. Een goed management is essentieel voor het efficiënt en effectief functioneren van elk bedrijf. Het managementconcept is echter vaag en moeilijk te definiëren. Derhalve wordt eerst de managementproblematiek van individuele agrarische bedrijven besproken en afgebakend, waarbij aandacht wordt besteed aan de drie belangrijke managementfuncties: planning, uitvoering en evaluatie. Vervolgens wordt de invloed van de recentelijke ontwikkelingen in computertechnologie op het management en op het MIS-concept besproken. Twee potentiële toepassingen van MIS worden gepresenteerd: DSS en ES. Een DSS kan worden omschreven als een MIS primair gericht op het ondersteunen van het besluitvormingsproces. Een DSS helpt de gebruiker bij het opvragen van gegevens en bij het genereren en testen van alternatieve oplossingen gedurende de probleemoplossende fase. De gebruiker kan doorgaans beschikken over een serie modellen die onderdeel zijn van een DSS. Een ES is een andere MIS-toepassing en kan worden gedefinieerd als een computerprogramma waarin de kennis van een expert gebruikt wordt ter verkrijging van een hoog prestatieniveau op een klein probleemgebied. Een ES neemt zoveel mogelijk dezelfde beslissingen als de menselijke expert en kan derhalve beschouwd worden als een modellering van het menselijke redeneerproces. De huidige uitdaging in het ontwikkelen van MIS is gelegen in het inbouwen van DSS en ES, waardoor een effectief instrument voor agrarische managers wordt verkregen. Dit dient evenwel te geschieden binnen een algemeen raamwerk voor geïntegreerde informatiesystemen. In Nederland vormt het informatiemodel een dergelijk raamwerk.

2. INDIVIDUELE BEDRIJFSANALYSE

Het tweede onderdeel van deze studie betreft de individuele bedrijfsanalyse. Individuele bedrijfsanalyse kan kortweg worden omschreven als de globale analyse van technische en economische bedrijfsgegevens om sterke en zwakke elementen in het management op te sporen. In hoofdstuk 2 wordt een systematische en objectieve methode voor individuele bedrijfsanalyse beschreven en bediscussieerd. Deze methode omvat drie typen analyse: (1) trend analyse, waarbij de actuele bedrijfsresultaten vergeleken worden met op het verleden gebaseerde voorspellingen, (2) vergelijkende analyse, waarbij de actuele bedrijfsresultaten vergeleken worden met gemiddelde resultaten van vergelijkbare bedrijven en (3) vergelijkende trend analyse, waarbij de ontwikkeling van het bedrijf vergeleken wordt met de gemiddelde ontwikkeling van vergelijkbare bedrijven. In elke type analyse worden de volgende fasen onderscheiden: opsporing van afwijkingen, weging van afwijkingen, nadere analyse van afwijkingen en eind-evaluatie van de individuele bedrijfsresultaten.

Bovenstaande methode is toegepast op de analyse van technische en economische gegevens van zeugenbedrijven en is vervolgens ingebouwd in CHESS. Het onderdeel van CHESS dat betrekking heeft op de individuele bedrijfsanalyse is modulair van opbouw en bestaat uit een DSS en drie ES. Het DSS identificeert en beoordeelt de importantie van relevante afwijkingen tussen de bedrijfsresultaten en de vergelijkingswaarden. De output van de DSS wordt gebruikt als input voor de drie ES, die sterke en zwakke elementen proberen te vinden door combinatie en evaluatie van de door de DSS gevonden afwijkingen. Als instrument voor beslissingsondersteuning kan CHESS tevens worden gebruikt ter bepaling van het maximale bedrag dat kan worden uitgegeven om de sterke elementen te behouden en de zwakke te verbeteren.

In hoofdstuk 3 wordt de procedure beschreven, waarmee het onderdeel individuele bedrijfsanalyse van CHESS gevalideerd is. Validatie kan in dit geval worden omschreven als het vergelijken van CHESS met de geobserveerde werkelijkheid. Validatie wordt in het algemeen gezien als een moeilijke maar belangrijke stap in het ontwikkelen van computersystemen. Dit is met name van toepassing op ES omdat daarbij symbolische, probleem-oplossende technieken en heuristieken worden gebruikt voor het afleiden van conclusies. De in dit hoofdstuk beschreven validatie bestond uit een gevoeligheidsanalyse voor het valideren van zowel het DSS als de drie ES afzonderlijk en uit een praktijktest voor de validatie van CHESS als geheel. Deze praktijktest resulteerde in een overeenkomst van ca. 60% tussen de analyses van de experts en die van CHESS. In slechts 4% van de gevallen was sprake van een duidelijke foutieve c.q. afwijkende classificatie door CHESS. Hieruit kan de conclusie worden getrokken dat de expertise van de experts met succes in CHESS is ingebouwd. CHESS toont zich een veelbelovend instrument voor het uitvoeren van - theoretisch correcte en algemeen toegankelijke - individuele bedrijfsanalyses.

3. OPTIMALISATIE VAN HET VERVANGINGSBELEID BIJ ZEUGEN

Het derde onderdeel van de studie is gericht op één van de mogelijke sterke of zwakke elementen die voort kunnen komen uit de individuele bedrijfsanalyse: het vervangingsbeleid bij zeugen. In hoofdstuk 4 wordt een (stochastisch) dynamisch programmeringsmodel (DP-model) geïntroduceerd. In het DP-model, dat aan CHESS is toegevoegd, wordt het economisch optimale vervangingsbeleid bij zeugen bepaald. Het doel bij het bepalen van het optimale beleid is het maximaliseren van de contante waarde van het verwachte saldo per zeug per jaar te behalen met de aanwezige zeug en de opeenvolgende opfokzeugen gedurende een gegeven planninghorizon. Naast verschillen in leeftijd (pariteit) houdt het DP-model rekening met het produktieniveau tijdens de laatste en voorlaatste pariteit en bovendien met het aantal keren terugkomen in de huidige pariteit. Een belangrijk punt van onderzoek in dit hoofdstuk is hoe het hoofd geboden kan worden aan het grote aantal toestands- en beslissingsvariabelen dat door het DP-model wordt omvat. Dit heeft geresulteerd in een alternatieve structuur van het DP-model. Verder is een gevoeligheidsanalyse uitgevoerd om inzicht te krijgen in de mogelijkheden voor het verkleinen van de omvang van het model. Hierbij is de kwaliteit van de te verkrijgen resultaten afgewogen tegen de hoeveelheid tijd die nodig is om de berekeningen op de PC uit te voeren. Beide variabelen zijn met name gevoelig voor reducties in het maximale aantal pariteiten dat in het model wordt toegestaan. In de uitgangssituatie neemt de optimalisatie 7 minuten en 18 seconden in beslag op een PC met een 80286 micro-processor en een 80287 co-processor.

De zoötechnische-economische aspecten van het DP-model worden in hoofdstuk 5 beschreven. Naast het bepalen van het economisch optimale vervangingsbeleid berekent het model de gebruikswaarde van de zeug. Onder de gebruikswaarde wordt verstaan het verwachte saldo bij aanhouden van de zeug tot het optimale tijdstip voor vervanging in plaats van onmiddellijke vervanging. Met dit kengetal kunnen zeugen binnen een bedrijf worden gerangschikt op basis van toekomstige winstgevendheid. Het kengetal kan daarom worden gebruikt als leidraad voor het vervangen van individuele zeugen. Rekening houdend met de kansen op gedwongen afvoer, resulteert het optimale vervangingsbeleid van zeugen in een gemiddelde gebruiksduur van 5.5 worpen. De daarmee corresponderende contante waarde van het verwachte saldo per zeug per jaar bedraagt 852 gulden. De economisch optimale gebruiksduur voor gemiddeld producerende zeugen is 9 worpen. Het optimale vervangingsbeleid is sterk afhankelijk van het verschil tussen de kosten van de vervangende opfokzeug en de slachtwaarde van de afgevoerde zeugen. Drachtigheidskansen hebben tevens een grote invloed op het verwachte saldo, het vervangingspercentage en de gemiddelde gebruiksduur.

Vervangingsbeslissingen worden doorgaans niet alleen gebaseerd op de produktieve en reproduktieve eigenschappen van de zeugen, maar ook op de meer kwalitatieve karakteristieken zoals beenproblemen, moedereigenschappen en uierkwaliteit (hoofdstuk 6). Daarom is CHESS eveneens uitgebreid met een ES voor de economische optimalisatie van het vervangingsbeleid gericht op dergelijke meer kwalitatieve karakteristieken. Het ES is gekoppeld aan het DP-model en het gebruikt de DP-resultaten als input. Het redeneerproces van het ES heeft betrekking op drie belangrijke punten: (1) duidelijk zichtbare afwijkingen aan de zeug, (2) afwijkingen in het aantal gespeende biggen in relatie met (3) afwijkingen in de uniformiteit van de toom biggen. Afwijkingen van het eerste type leiden altijd tot het advies om de zeug te vervangen door een opfokzeug. Nadat afwijkingen van het tweede en/of derde type gevonden zijn vindt er een economische bedrijfsspecifieke weging plaats door het ES. Vervolgens worden de door het DP-model berekende gebruikswaarden van de zeugen door het ES aangepast op basis van deze economische gewichten. De gebruikte methodiek voor het verkrijgen van de benodigde kennis (vuistregels, heuristieken) voor het ES omvatte directe interviews met een expert. Hierbij werd gebruik gemaakt van werkelijke en voorbeeld-problemen. De resultaten van validatie duiden op een hoge overeenkomst tussen de rangschikking van 30 test-scenario's door CHESS en door twee experts. Eén van deze experts werd reeds geraadpleegd voor het verkrijgen van de kennis voor het ES. De aangepaste gebruikswaarden van de zeugen lijken zeer geschikt als leidraad voor het nemen van vervangingsbeslissingen bij individuele zeugen.

4. BELANGRIJKSTE CONCLUSIES

De belangrijkste conclusies uit dit proefschrift zijn:

- Recentelijke ontwikkelingen in computertechnologie maken het mogelijk dat realistische management-beslissingen op agrarische bedrijven met de personal computer ondersteund kunnen worden. Aangezien toepassingen op de personal computer geschikt zijn voor gebruik in het veld, neemt de relevantie van beslissingsondersteuning op het bedrijf zelf toe.
- Geïntegreerde decision-support-systemen en expertsystemen maken het beter mogelijk om belangrijke problemen op het gebied van de individuele bedrijfsanalyse en op het gebied van het vervangingsbeleid bij zeugen te formuleren en op te lossen.
- Bij het opsporen van sterke en zwakke elementen in het management van individuele - zeugen - bedrijven, verdient het aanbeveling de volgende drie typen analyse uit te voeren: (1) trend analyse, waarbij de actuele bedrijfsresultaten vergeleken worden met op het verleden gebaseerde voorspellingen, (2) vergelijkende analyse, waarbij de actuele bedrijfsresultaten vergeleken worden met gemiddelde resultaten van vergelijkbare bedrijven en (3) vergelijkende trend analyse, waarbij de ontwikkeling van het bedrijf vergeleken wordt met de gemiddelde ontwikkeling van vergelijkbare bedrijven.
- Bij het gecomputeriseerd uitvoeren van een individuele bedrijfsanalyse dient de top-down benadering toegepast te worden: d.w.z. eerst een globaal economisch overzicht van het bedrijf opstellen en pas vervolgens een gerichte keuze met betrekking tot de gedetailleerde analyse van relevante (deel-)problemen maken, zoals bijvoorbeeld het vervangingsbeleid.

- Bij het ondersteunen van de vervangingsbeslissing bij zeugen verdient het aanbeveling de toekomstige winstgevendheid van individuele zeugen te baseren op zowel de kwantitatieve produktieve en reproduktieve eigenschappen van de zeug als op de meer kwalitatieve eigenschappen met inbegrip van beenwerk, moedereigenschappen en uierkwaliteit.
- Validatie van expertsystemen is moeilijk maar mogelijk.

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CURRICULUM VITAE

Rutgerus Bernardus Maria Huirne werd op 4 oktober 1962 geboren te Eibergen (Gelderland). In 1981 behaalde hij het Atheneum-diploma aan de Haaksbergse Scholengemeenschap te Haaksbergen. In september van dat jaar begon hij aan zijn studie Economie aan de Landbouwhogeschool te Wageningen, met als hoofdvakken Agrarische Bedrijfseconomie en Optimaliseringstechnieken en als bijvakken Veevoeding en Industriële Bedrijfskunde. De studie werd in september 1986 afgerond. In 1987 werd hem door de Stichting Wageningenfonds de prof. C.T. de Wit scriptieprijs toegekend voor de scriptie "Een stochastisch dynamisch programmeringsmodel ter ondersteuning van de varkenshouder bij het nemen van de vervangingsbeslissing bij zeugen", resultaat van een doctoraalonderzoek bij de vakgroepen Agrarische Bedrijfseconomie en Wiskunde. Sinds 1 september 1986 is hij als universitair docent verbonden aan de vakgroep Agrarische Bedrijfseconomie van de Landbouwuniversiteit te Wageningen. Tijdens de NAIC'90-AIT'90-conferentie in 1990 kreeg het in dit proefschrift beschreven management-informatiesysteem CHESS de prijs voor de beste toepassing. De prijs werd toegekend door de Nederlandse Vereniging voor Kunstmatige Intelligentie (NVKI) en de Werkgroep Expertsystemen van het Nederlands Genootschap voor Informatica (NGI).